

# SeaWiFS and MODIS Aerosol Optical Thickness matchups Using Sun Photometers

Christophe Pietras, Kirk Knobelspiesse and Sean Bailey



SIMBIOS Project, Code 970.2

# Outline

- **SIMBIOS Program and Project Overview**
- **SeaBASS Database and Holdings**
- **SIMBIOS Instrument Pool**
- **AOT Match-up Criteria**
- **SeaWiFS and MODIS Products**
- **SeaWiFS Matchups**
- **MODIS Terra Matchups**
- **Conclusions and Future Work**

# SIMBIOS Program

<http://simbios.gsfc.nasa.gov>

The **S**ensor **I**ntercomparison and **M**erger for **B**iological and **I**nterdisciplinary **O**cean **S**tudies (SIMBIOS) Program goal is to assist the international ocean color community in developing a multi-year time series of calibrated radiances that transcend the spatial and temporal boundaries of individual missions.

## Objectives

- Ensure development of internally consistent research products and time series from multiple satellite ocean color data sources
- Develop methodologies for cross-calibration of satellite ocean color sensors
- Develop methodologies for merging data from multiple ocean color missions
- Promote cooperation between ocean color projects
- Serve as a prototype for other Earth observation programs

# SIMBIOS Program Structure

- **SIMBIOS Science Team**

- NRA-96 (1997-2000): 21 US & 5 international investigations
- NRA-99 (2001-2003): 20 US & 14 international investigations
- MODIS Oceans Team

- **SIMBIOS Project Office**

- Co-located with SeaWiFS (1996-2003)
- Technical, program management, science team coordination & NRA support
- Technical interface with space agencies (e.g., NASDA, CNES, ESA, KARI), other organizations (e.g., NIST, IOCCG, JRC, DLR), and programs (e.g., EOS, AERONET)

## Mission Feedback

- Science community input
- Comparison with other appropriate products
- New Mission
- Protocol development

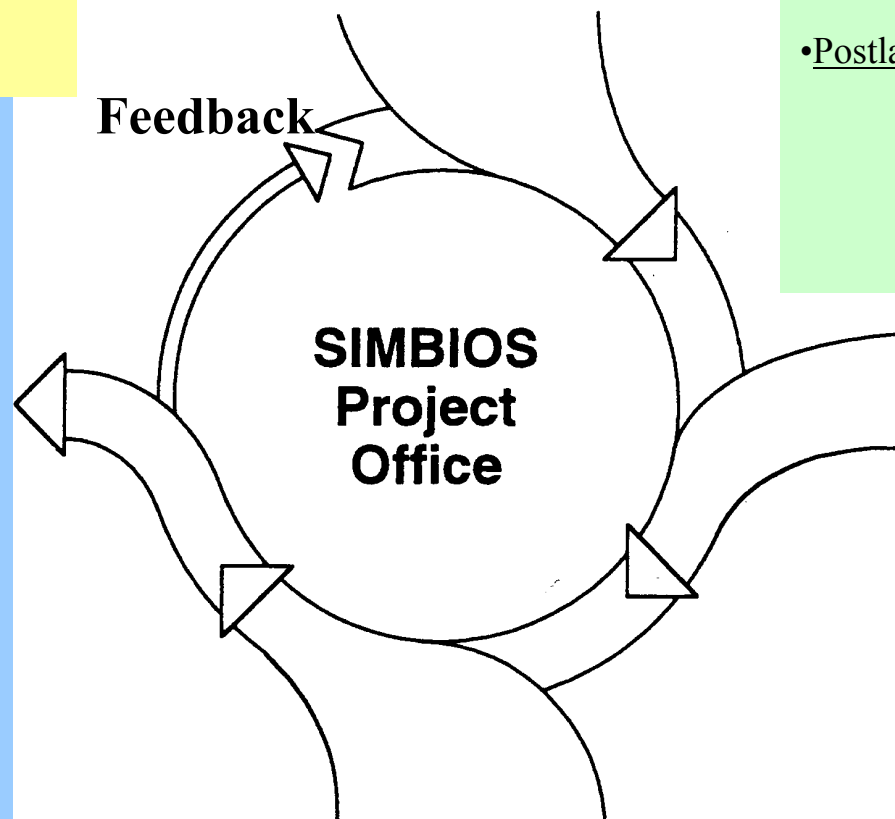
## Improved Products & Algorithms

- Reprocessing due to improvements in calibration, masks, binning schemes, product compatibilities, etc.
- New products from bio-geochemical fields, atmospheric fields, etc.
- Data distribution interface

## SeaDAS

- Satellite data processing software (CZCS, MOS, SeaWiFS, OCTS, OSMI and MODIS display)

## Satellite Data from Calibrated Sensors



## Calibration Strategy

### •Prelaunch

Lab. characterization & calibration (NIST traceable)

Solar calibration (transfer-to-orbit)

### •Postlaunch (operational adjustments)

Solar calibration (daily)

Lunar calibration (monthly)

MOBY  $L_{wn}$  time series for vicarious calibration


## *In Situ* Data

- Collection of bio-optical and atmospheric measurements (SIMBIOS PIs)
- *in situ* instrument calibration (Project round robin NIST-traceable )
- Data collection following Ocean Optics protocols
- Maintenance of an archive of calibrated and QC'd *in situ* data (SeaBASS)
- Calibrated instrument pool

## Product & Algorithm Validation

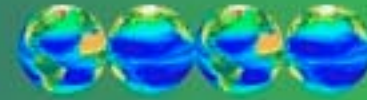
- Atmospheric & bio-optical algorithm validation and development (SIMBIOS PIs and project staff)
- Match-up analysis, satellite QC, time series evaluation, etc.

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# SeaBASS

*The SeaWiFS Bio-optical Archive and Storage System*



## HIGHLIGHTS

Local archive for bio-optical data and related oceanographic and atmospheric measurements

Data contributed by research groups from 43 institutions in 14 countries

Data uses include:

- (1) satellite ocean color data product validation
- (2) bio-optical algorithm development
- (3) climate, time series, and merger studies

31,000 data files from over 1,100 field campaigns, as of September 2002, including:

- (1) 10,000 continuous depth profiles
- (2) 220,000 phytoplankton pigment concentrations
- (3) 14,000 spectrophotometric scans
- (4) 13,000 discrete measurements of aerosol optical thickness

All data are accessible online:

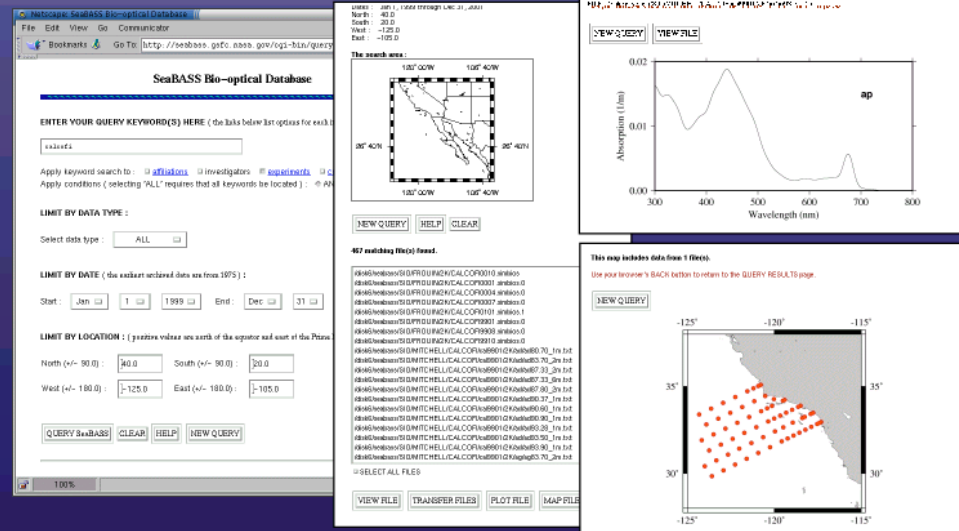
- (1) full access restricted to NASA-funded researchers
- (2) all data collected prior to 31 December 1999 publicly available
- (3) public data contributed to NOAA NODC

Over 62,000 data files distributed from 1 January to 31 July 2002

See also NASA/TM-2002-211617, published this September

<http://seabass.gsfc.nasa.gov>

## ONLINE ACCESS

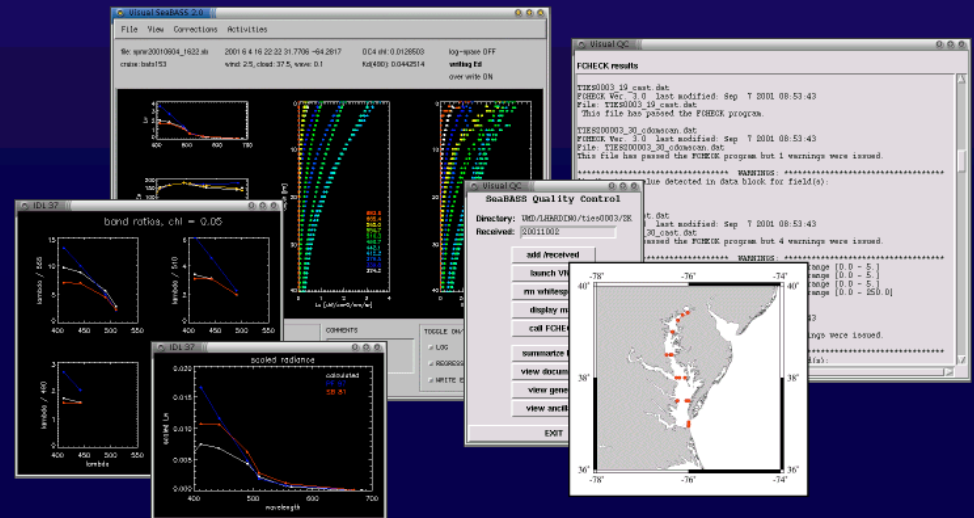


Data are collected by the  
**SIMBIOS Team members and  
other investigators**

## SEABASS data are

- collected according to the SIMBIOS measurement protocol documented in NASA Technical Memorandums
- processed, QC'd and archived in SeaBASS
- available online

## QUALITY CONTROL





FRSR



MPL



Microtops II



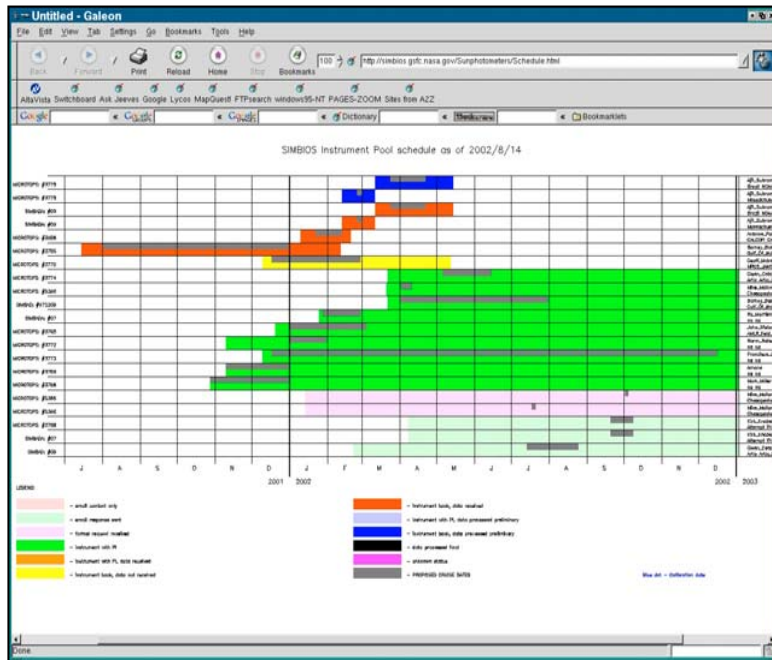
SIMBADA

# SIMBIOS Instrument Pool

- Microtops II Sun Photometer (14)
  - Hand held sun photometer, bands at 440, 500, 675, 870 and 936nm
  - Cross calibrated regularly (every 90 days) with respect to AERONET CIMELs
- SIMBAD Sun Photometer/Above water radiometer (2)
  - Hand held sun photometer and above water radiometer with bands at 443, 490, 560, 670 and 865nm
  - Cross calibrated regularly (every 90 days) with respect to AERONET CIMELs
- SIMBADA Sun Photometer/Above water radiometer (2)
  - Hand held sun photometer and above water radiometer with bands at 350, 380, 412, 443, 490, 510, 565, 620, 670, 750 and 865nm
  - Cross calibrated regularly (every 90 days) with respect to AERONET CIMELs
- Fast Rotating Shadowband Radiometer -FRSR- (12)
  - Automated Shadowband Radiometer deployed by the Brookhaven National Laboratory (Dept. of Energy) as part of the Portable Radiation Package (PRP)
  - Measures sky radiance and AOT at 410, 500, 615, 680 and 870nm
- Micro-Pulse LIDAR -MPL- (1)
  - Autonomous Eye safe LIDAR at 523nm
- CIMEL Sun Photometer (14)
  - Coastal and maritime sun photometers, given to AERONET project

# SIMBIOS Instrument Pool Management

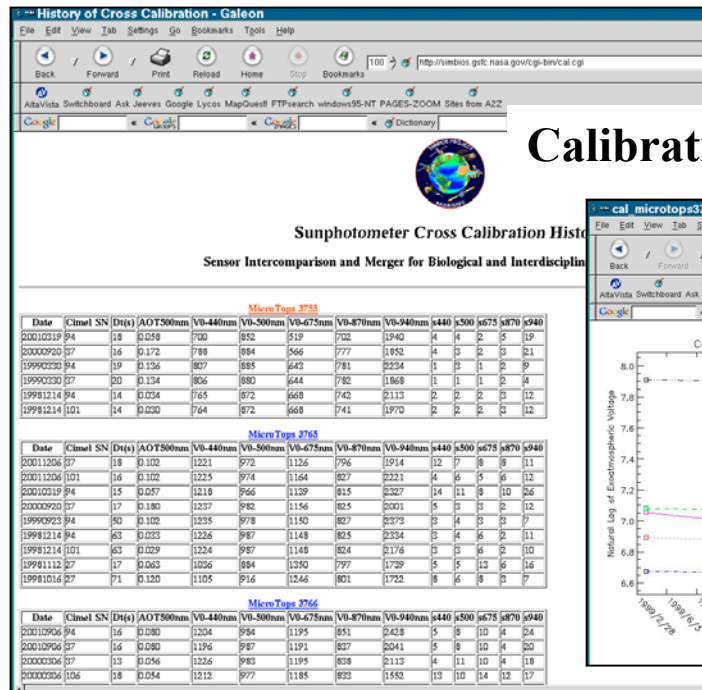
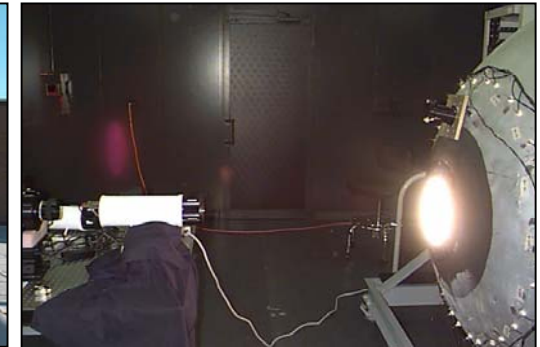
**Scheduling for deployment,  
calibration and data processing**



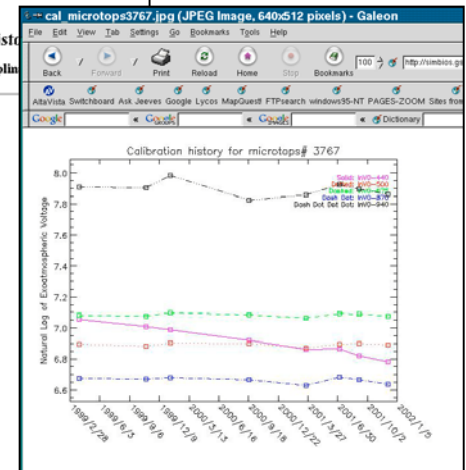
## Sun Calibration



## Radiance Calibration



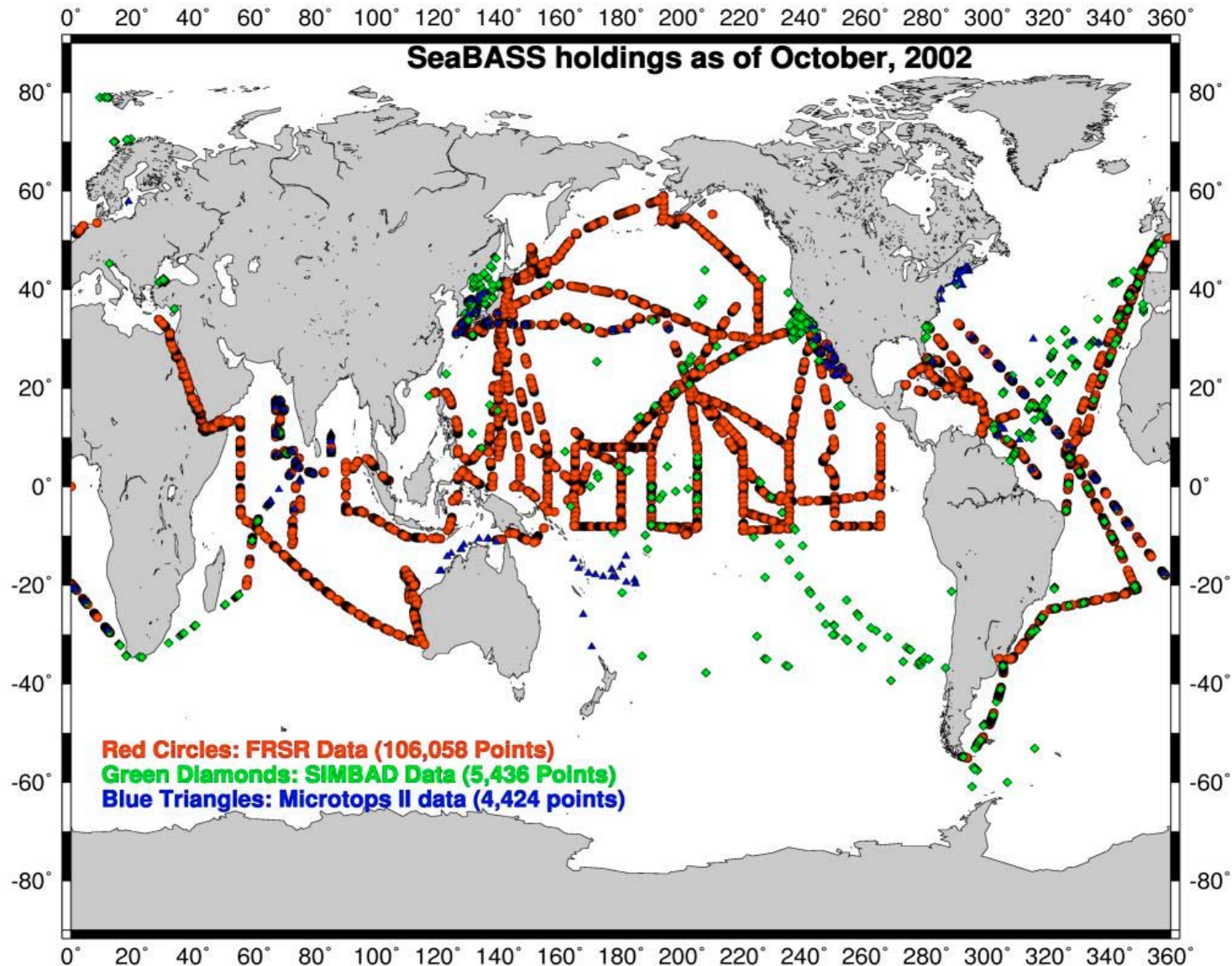
## Calibration History



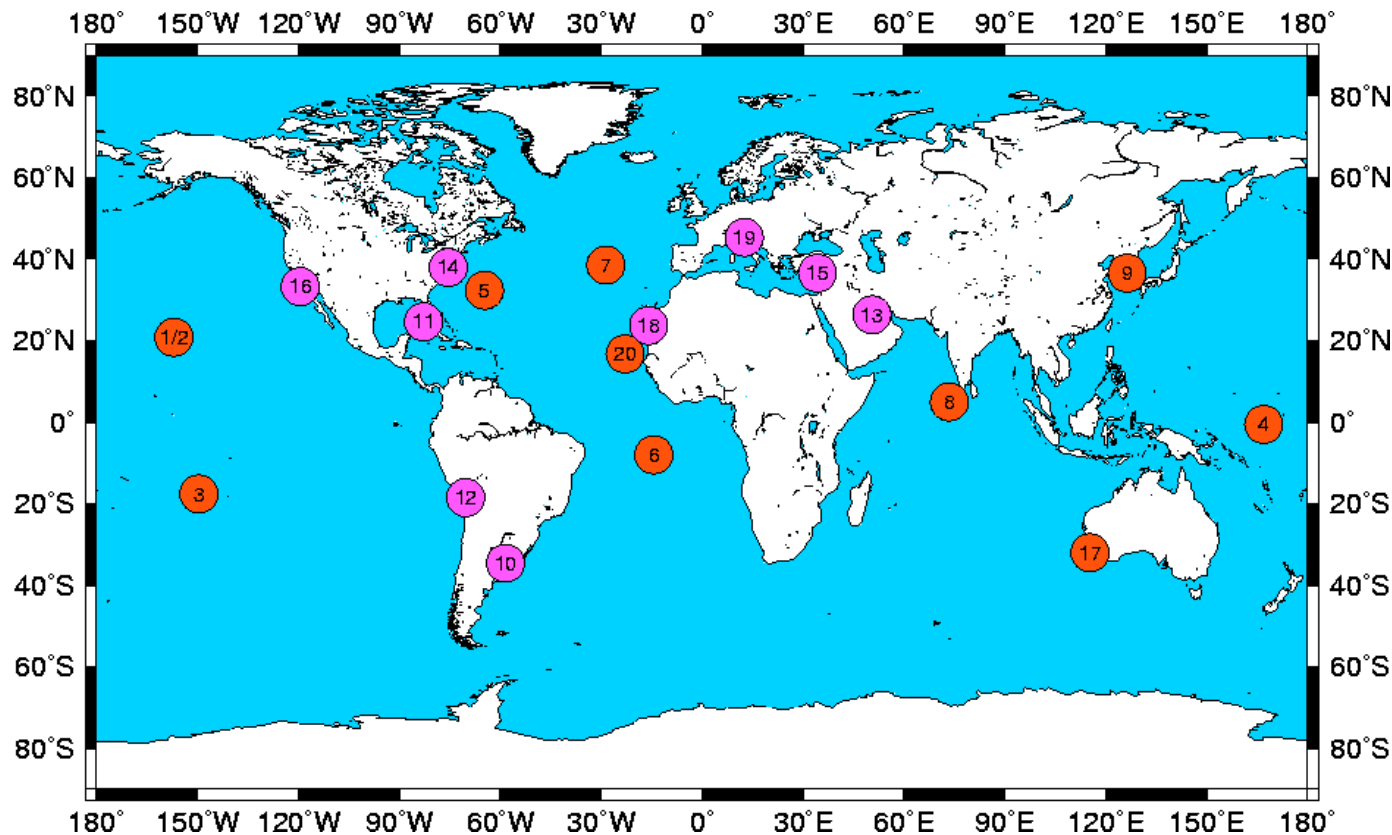
<http://simbios.gsfc.nasa.gov/sunphotometers/>

# SeaBASS Open Ocean Atmospheric Data set

**Over 300 cruises supported by SIMBIOS since 1997**



# AERONET Data Set




- Coastal sites
- Pacific Ocean maritime sites

- Lanai**
  - Coconut Island**
  - Tahiti**
  - Nauru Island**
  - Bermuda**
  - Ascension Island**
  - Azores**
  - Kaashidhoo**
  - Anmyon Island**
  - Puerto Madryn**
  - Dry Tortugas**
  - Arica**
  - Bahrain**
  - Wallops**
  - Erdemli**
  - San Nicolas Island**
  - Rottneest Island**
  - Dahkla**
  - Venice**
  - Capo Verde**
- (red denotes SIMBIOS supported sites)



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# Selection criteria

## *In situ*

- Apply **latest calibration**
- Remove **pointing errors** and use **cloud-free** measurements only
- **Average** +/- 1 hr around satellite overpass (SeaWiFS: noon, MODIS Terra: 10:30)

## SeaWiFS

- Use **L2 products**
- **1 km** (LAC) or **4 km** resolution (GAC)
- Size of the area of interest: **21x21 (LAC)** or **5x5 (GAC)** pixels
- Within area of interest, select **cloud-free, non-land** pixels within median +/- STD
- Use **average** if COV < 0.1 and > 50% are valid pixels

## MODIS Ocean

$$COV = \frac{STD}{Mean}$$

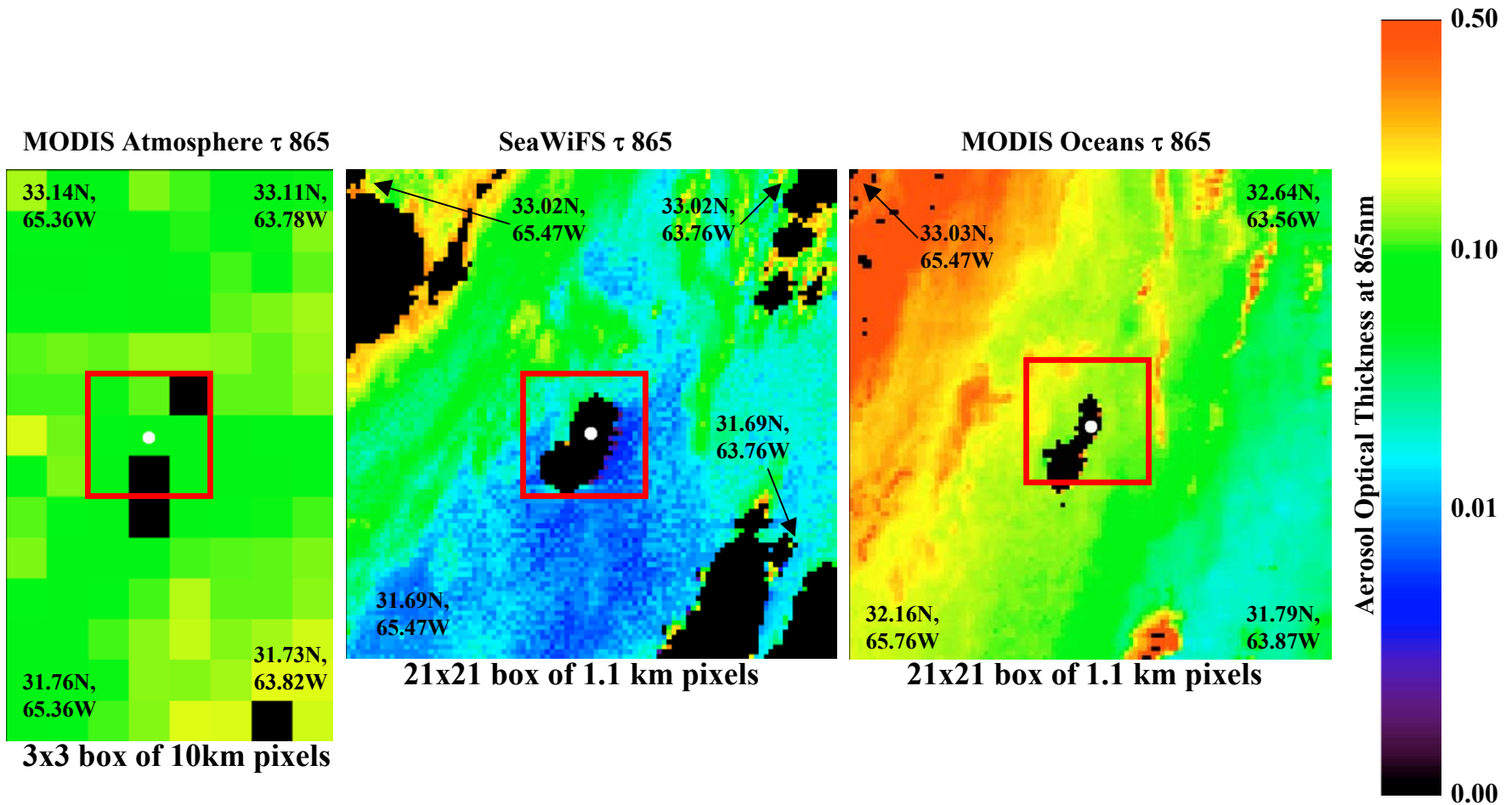
- Use **L2 products** (MOD37)
- **1 km** resolution
- Size of the area of interest: **21x21** pixels
- Within area of interest, select **cloud-free, non-land** pixels within median +/- STD
- Use **average** if COV < 0.1 and > 50% are valid pixels

## MODIS Atmosphere

- Use **L2 products** (MOD04)
- **10 km** resolution
- Size of the area of interest: **3x3** pixels
- Select **cloud-free, water** or **coastal** pixels
- Average if retrieval is performed and estimated aerosol parameter quality is “**good**” or “**very good**”

# Satellite AOT Product Examples

Images from different dates; not a comparison

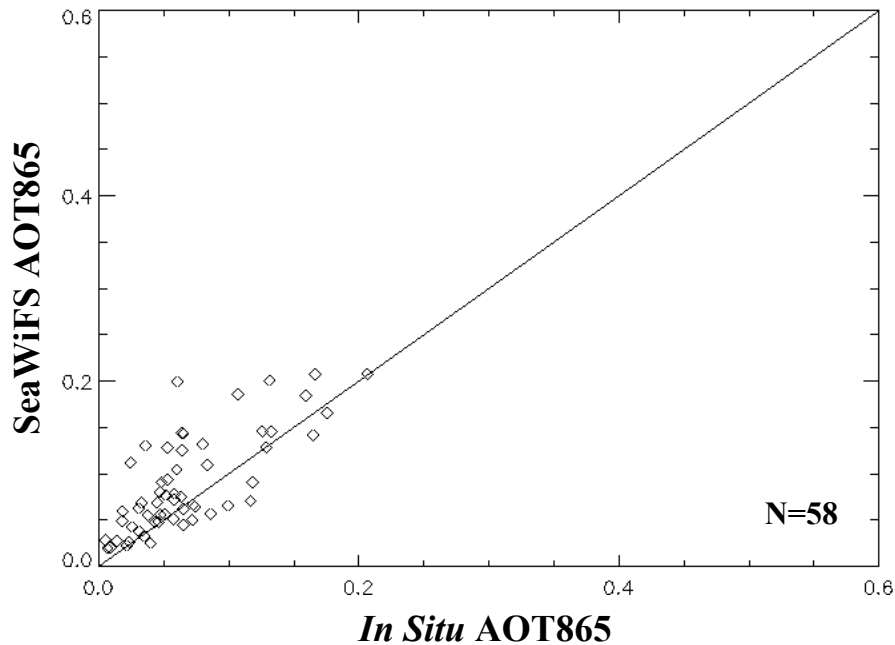


# SeaWiFS Matchups- *Open Ocean*

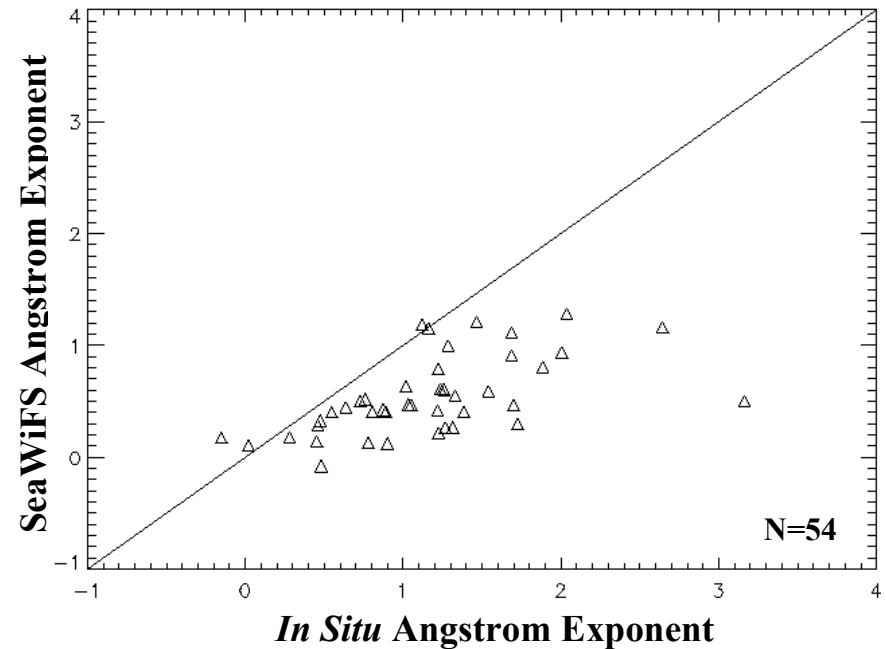
***In Situ* data is matched to spatially and temporally concurrent satellite data**

**Below are matchups for open ocean data collected with the SIMBAD and Microtops II sun photometers for AOT at 865nm and the Angstrom Exponent**

**SeaWiFS - *In Situ* matchups for AOT at 865nm**



**SeaWiFS - *In Situ* Angstrom Exponent matchups**





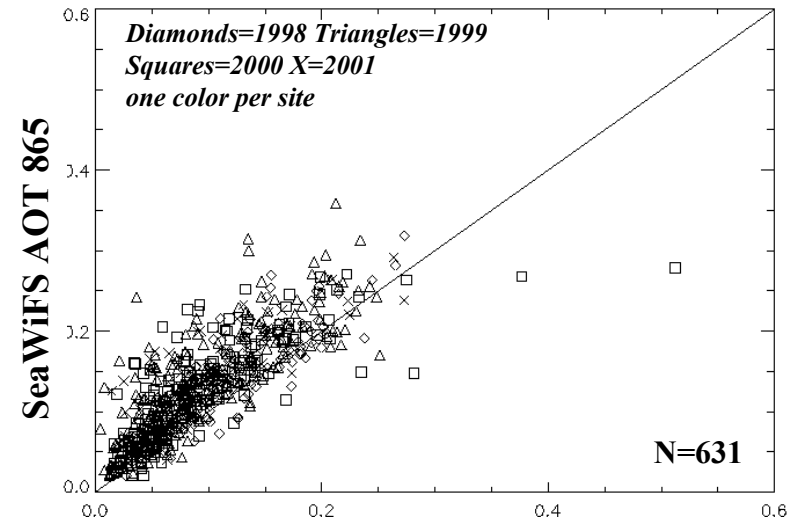
# SeaWiFS Matchups - Coastal and Maritime CIMELs



Sites:

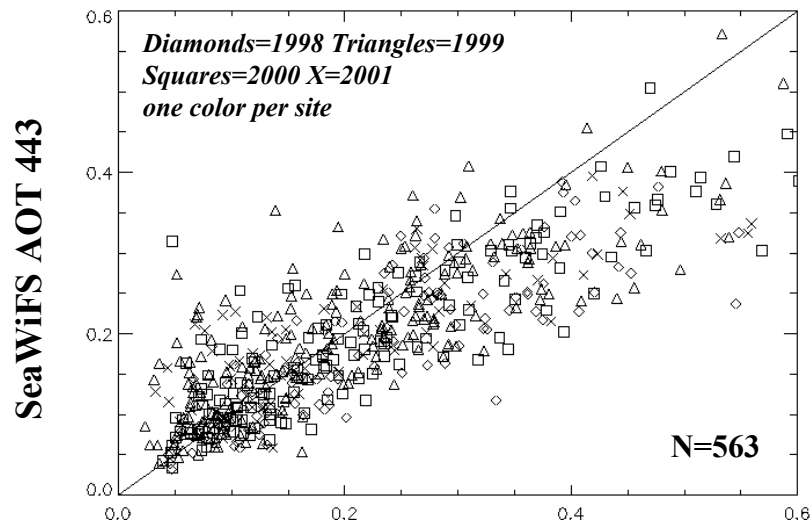
1. Lanai 2. Coconut Island 3. Tahiti 4. Nauru Island 5. Bermuda 6. Ascension Island
  7. Azores 9. Anmyon Island 11. Dry Tortugas 12. Arica 13. Bahrain 14. Wallops 15. Erdemli
- (red denotes SIMBIOS supported sites)

SeaWiFS - *In Situ* matchups for AOT 865nm



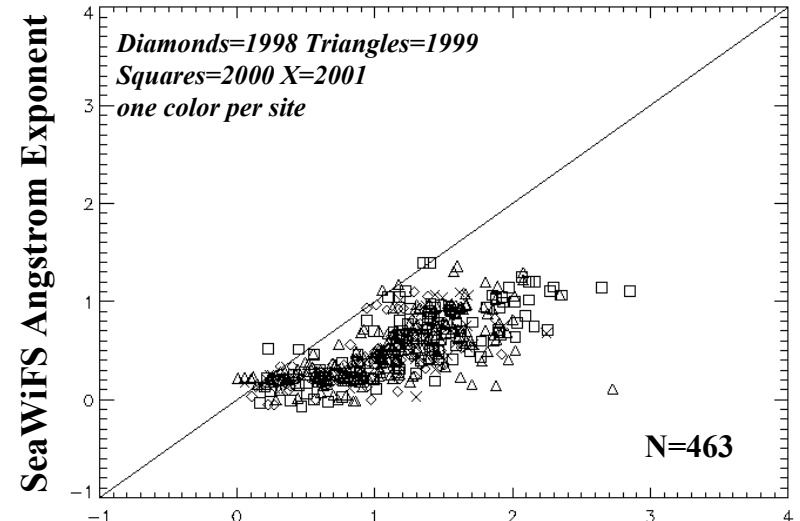
*In Situ* AOT 865

SeaWiFS - *In Situ* matchups for AOT 443nm



*In Situ* AOT 443

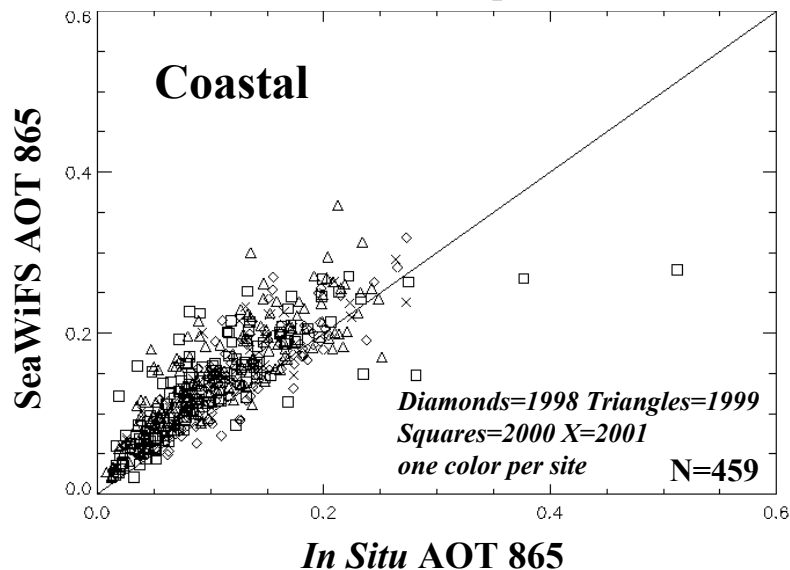
SeaWiFS - *In Situ* matchups for Angstrom Exponent



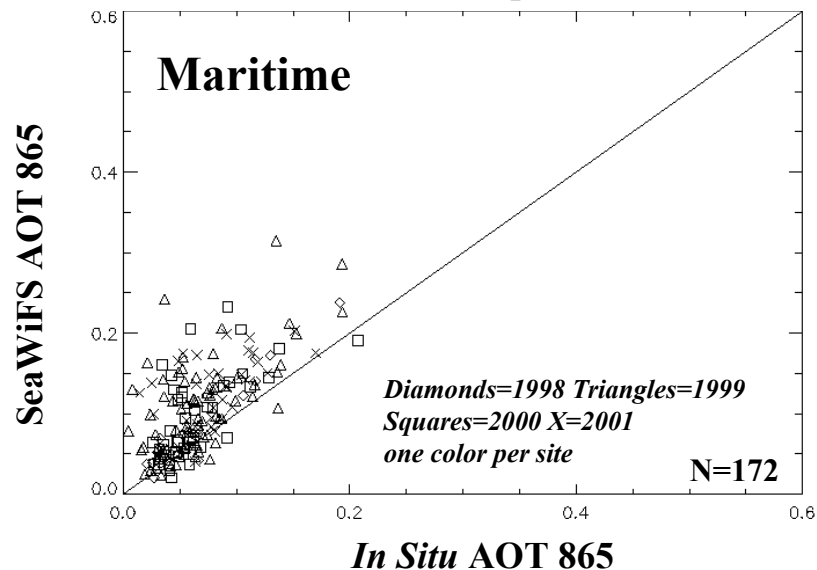
*In Situ* Angstrom Exponent

# Coastal and Maritime Site Comparison

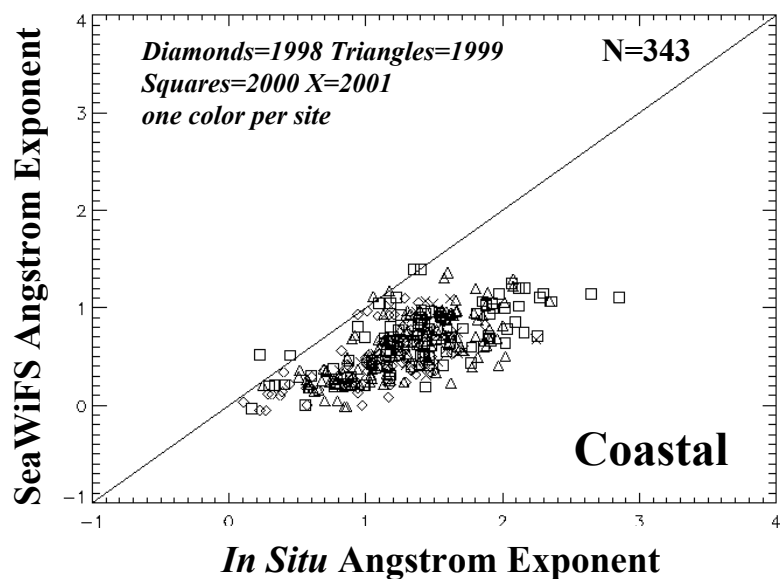
SeaWiFS - *In Situ* matchups for AOT 865nm



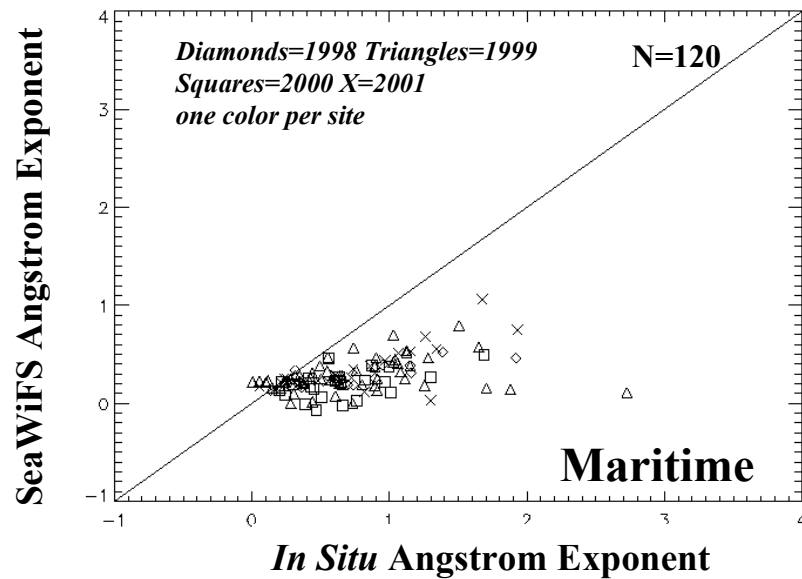
SeaWiFS - *In Situ* matchups for AOT 865nm




SeaWiFS - *In Situ* Angstrom Exponent matchups



SeaWiFS - *In Situ* Angstrom Exponent matchups



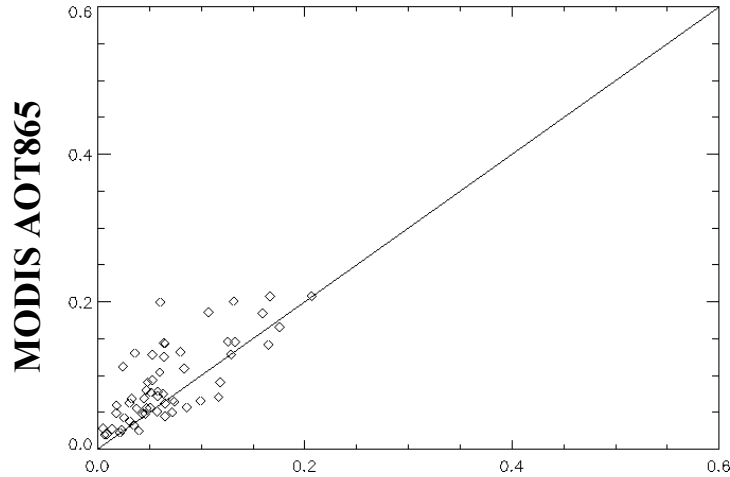
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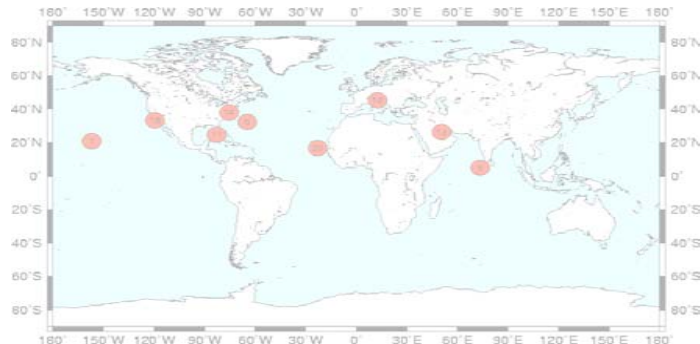
# MODIS Terra Matchups

## Open Ocean

MODIS Oceans - *In Situ* matchups for AOT at 865nm



Hand-held *In Situ* AOT865



Sites considered

1 Lanai - 5 **Bermuda** - 8 Kaashidhoo

11 **Dry Tortugas** - 13 Bahrain - 14 **Wallops**

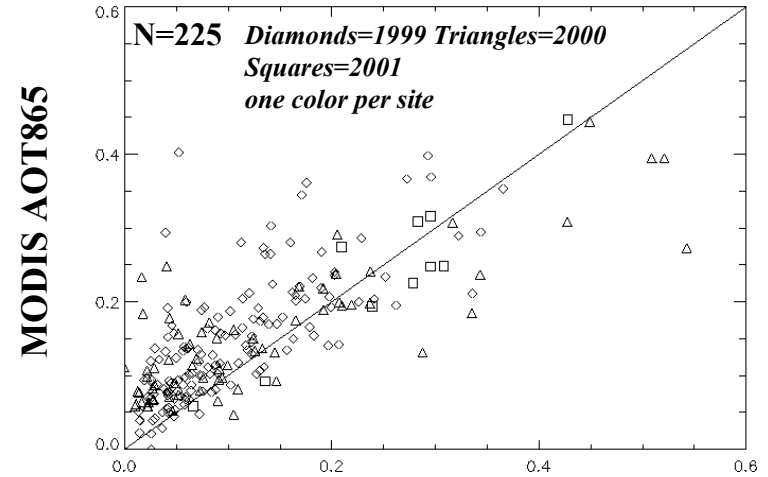
16 San Nicolas Island - 19 Venice - 20 **Capo Verde**

*red sites - used for MODIS Oceans and Atmosphere matchups*

*black sites - used for MODIS Atmosphere matchups only*

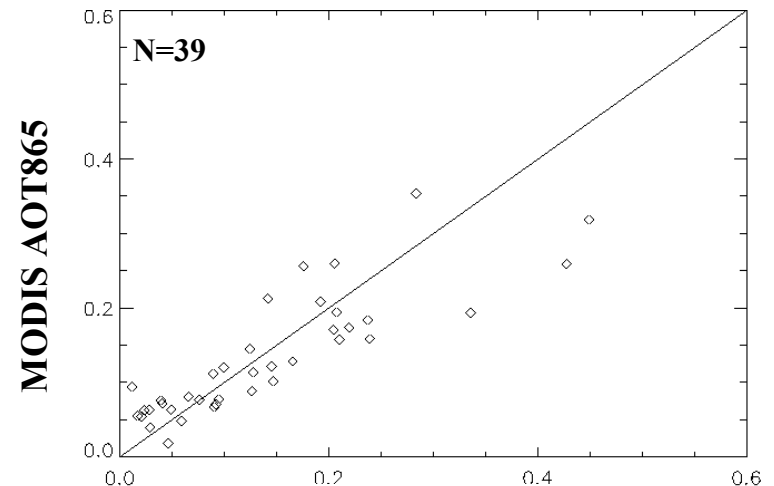
## Coastal and Maritime

MODIS Oceans



CIMEL *In Situ* AOT865

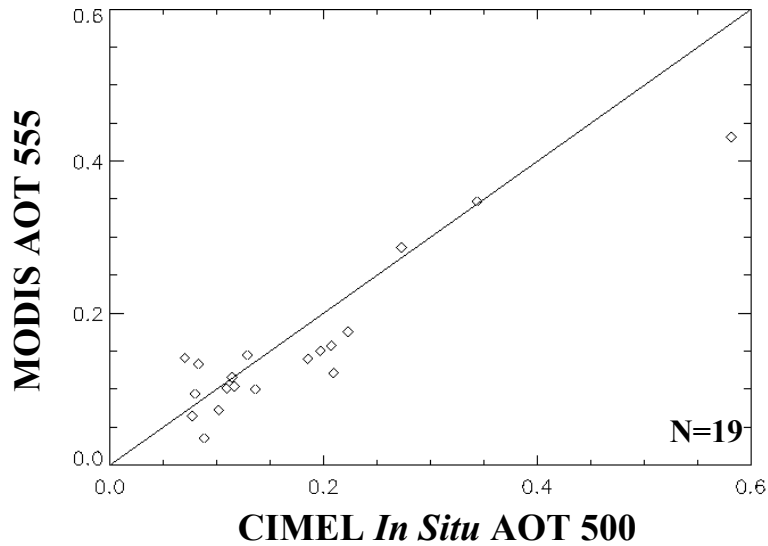
MODIS Atmosphere



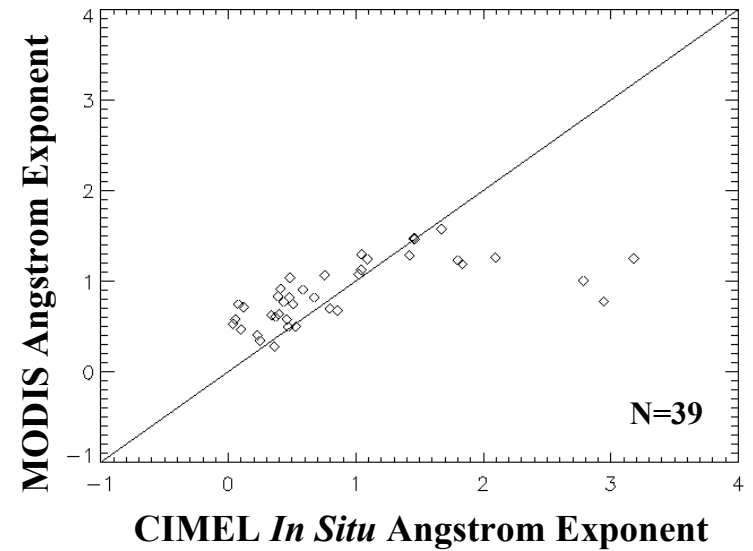
CIMEL *In Situ* AOT865

# MODIS Terra Matchups

**MODIS Atmosphere - *In Situ* matchups for AOT at 555nm**



**MODIS Atmosphere - *In Situ* Angstrom matchups**



# Atmospheric Correction Algorithms

## SeaWiFS

Wang and Gordon, 1994

$$\rho_w(765-865)=0$$

$$\varepsilon(765, 865) \rightarrow (P_a, \omega_a, \tau_a) \rightarrow \tau_a(865), \alpha(510) \\ (P'_a, \omega'_a, \tau'_a)$$

12 aerosol models

Improvement of the Algorithm by Christina Hsu

## MODIS Oceans

Wang and Gordon, 1994, Gordon and Voss, 1999 (<http://modis.gsfc.nasa.gov>)

$$\rho_w(750-865)=0$$

Similar to SeaWiFS but 16 models

$$\varepsilon(750, 865) \rightarrow (P_a, \omega_a, \tau_a) \rightarrow \tau_a(865)$$

16 aerosol models  $(P'_a, \omega'_a, \tau'_a)$

## MODIS Atmosphere

Kaufman and Tanre, 1998 (<http://modis.gsfc.nasa.gov>)

$$\rho_w(0.55)=0.5 \quad ; \quad \rho_w(\lambda)=0$$

$$\varepsilon_{sl} = \sqrt{\frac{1}{n} \sum_{\lambda_1}^{\lambda_n} \left( \frac{L_j^m - L_j^c}{L_j^m + 0.01} \right)^2} \quad L_j^c = \eta L_\lambda^s + (1 - \eta) L_\lambda^L \quad L_j^m \text{ is measured radiance}$$

$\text{MIN}(\varepsilon_{sl}) \rightarrow (L_\lambda^s, L_\lambda^L, \tau_a(555)) \& \forall \eta \rightarrow \text{“Best solution” } \tau_a(555)$

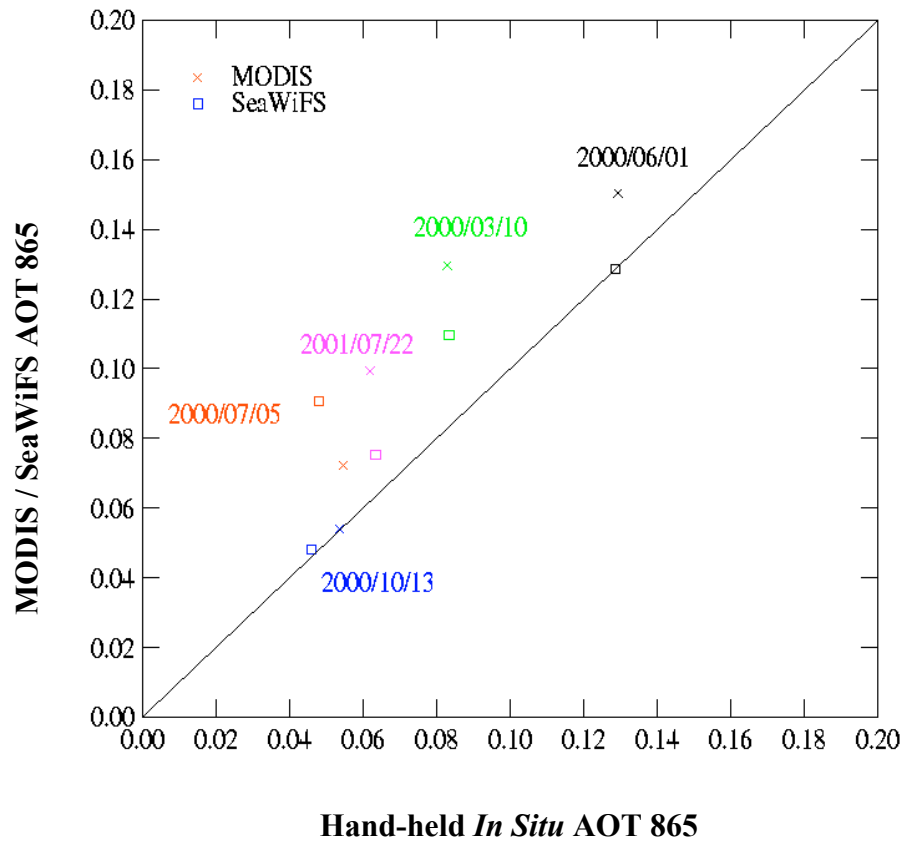
$\varepsilon_{sl} < 3\% \rightarrow \text{“Average solution” } \tau_a(\lambda)$

5 small modes and 6 large modes models are combined for  $\tau_a^{555} = [0, 0.2, 0.5, 1, 2]$

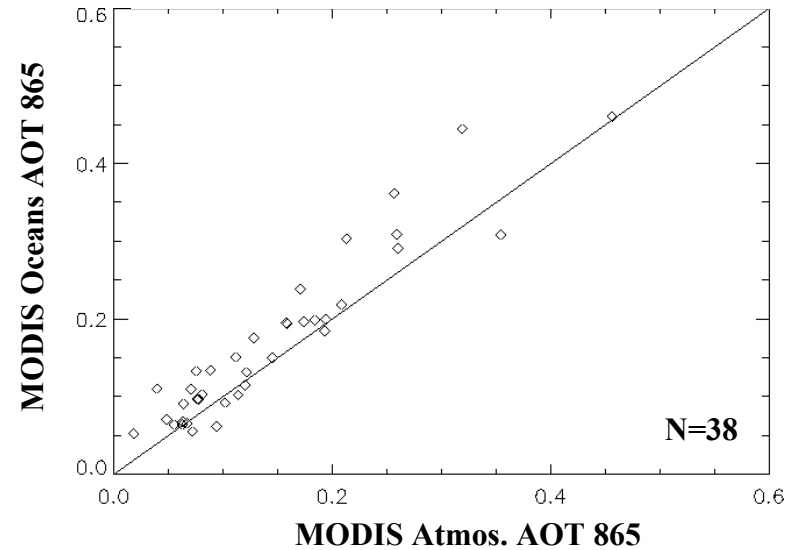
# SeaWiFS-MODIS Common Point Match-up Results

## Coastal and Maritime

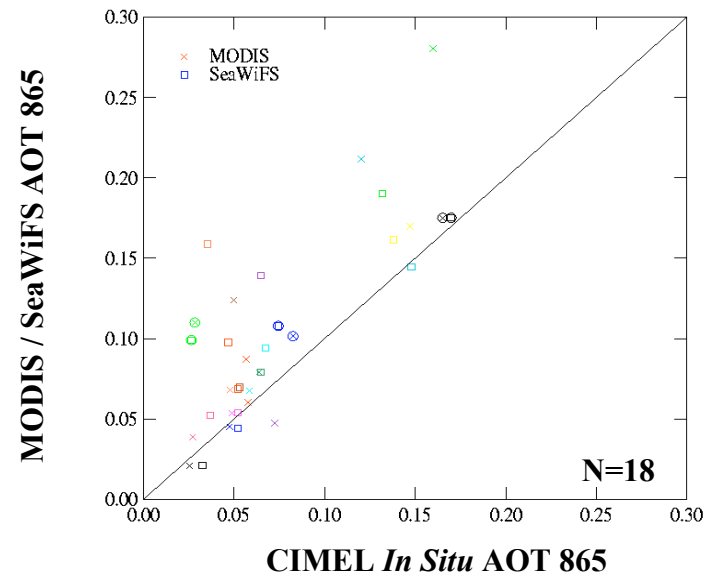
### Open Ocean



### MODIS Oceans and MODIS Atmosphere



### MODIS and SeaWiFS



# Conclusions

- **4 years of *In Situ* data have provided a strong database for SeaWiFS validation over Open Oceans**
- **SeaWiFS matchups show**
  - a slight overestimation of the AOT at 865 nm
  - a slight underestimation of AOTs at shorter wavelengths
  - an underestimation of the Angstrom exponent and a smaller range in values than *in situ* measurements
- **Preliminary validation was conducted using MODIS Terra products, results are encouraging**
- **SIMBIOS expanded AERONET to provide coverage of coastal and maritime aerosols**
- **The software and protocols are in place to do matchups across missions**

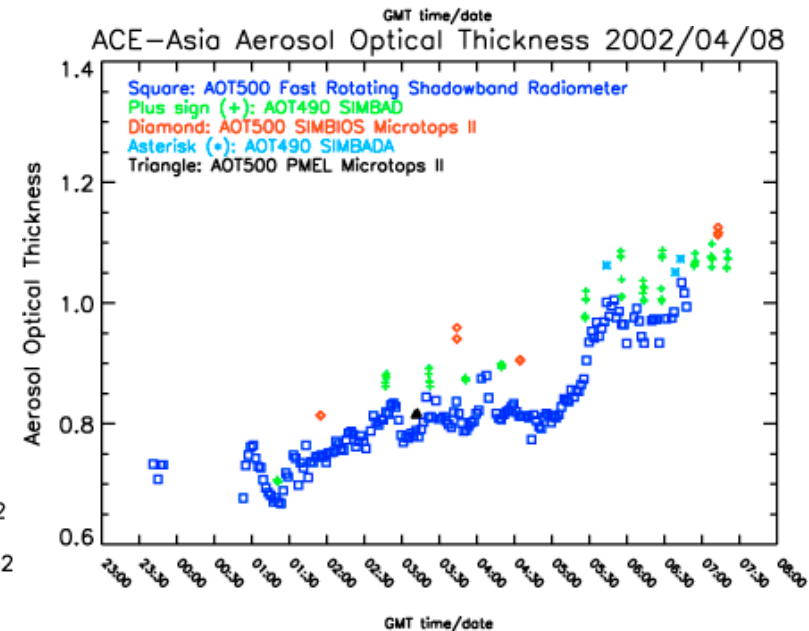
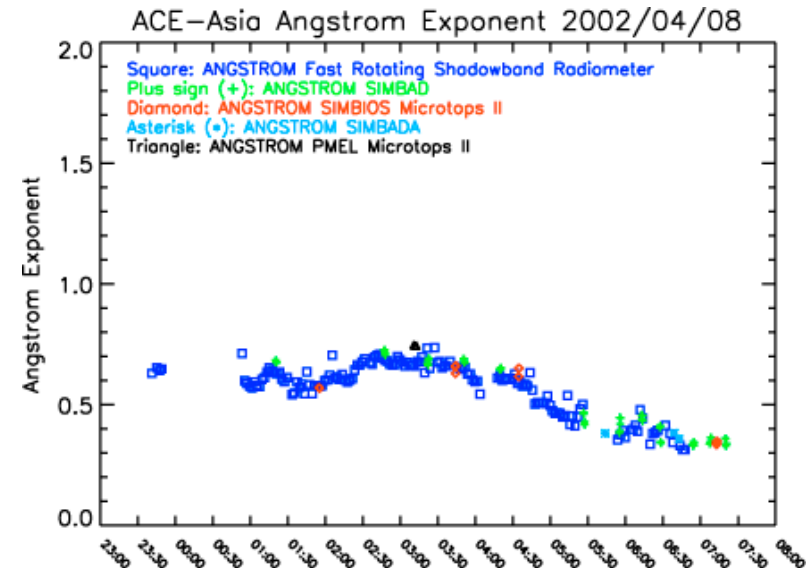
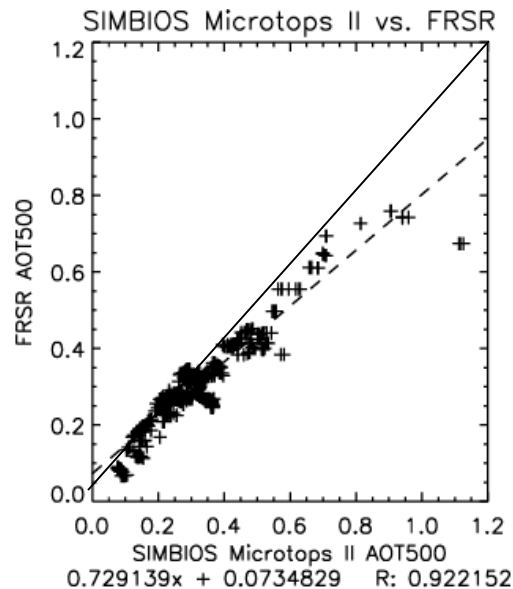
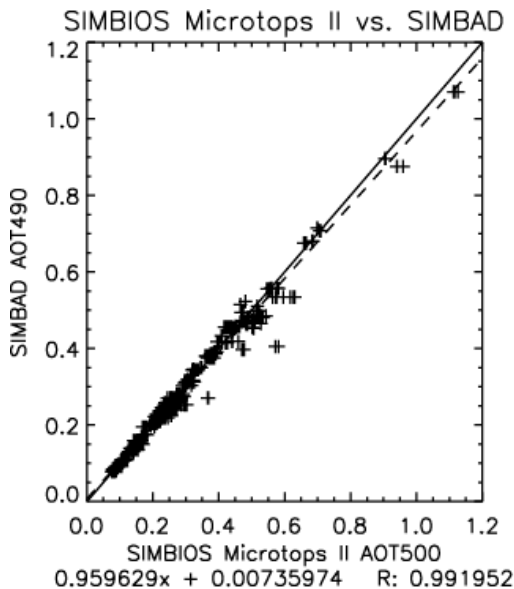


# Work in Progress

- **SeaWiFS validation results show the need to revisit the atmospheric correction models, the maritime model in particular**
- **Statistical analysis of entire data set underway, goals are**
  - determine if AOT data show lognormal and Angstrom exponent normal distributions
  - compute global AOT and Angstrom exponent statistics
  - identify maritime data, calculate statistics
  - compare maritime statistics to AERONET coastal statistics
  - build new model set, with both SeaBASS and AERONET data (Frouin & Gross, SIO)
- **Confident this can now be done with SeaBASS data**
  - Microtops II sun pointing error problem resolved (Knobelspiesse, Fargion and Pietras, 2002, in press)
  - Uncertainty analysis performed for Microtops II, SIMBAD and FRSR
  - Concurrent measurements in variety of atmospheric situations (ACE-Asia) show agreement between instrument types and calibration (Miller, et al. 2002, Frouin, et al. 2002, in progress)

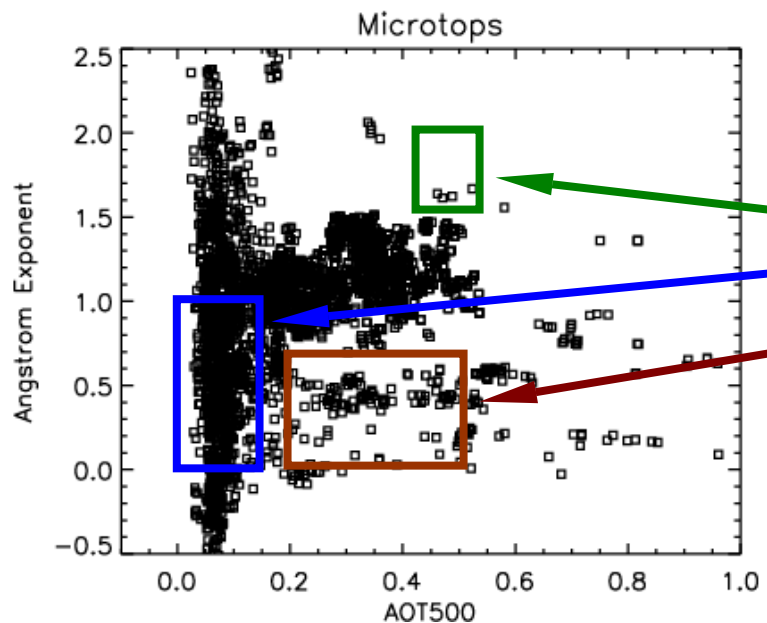
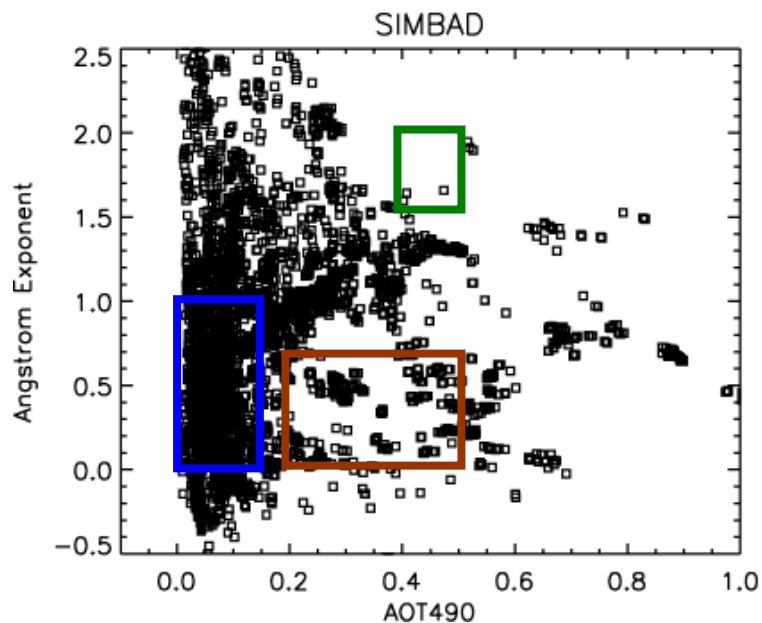
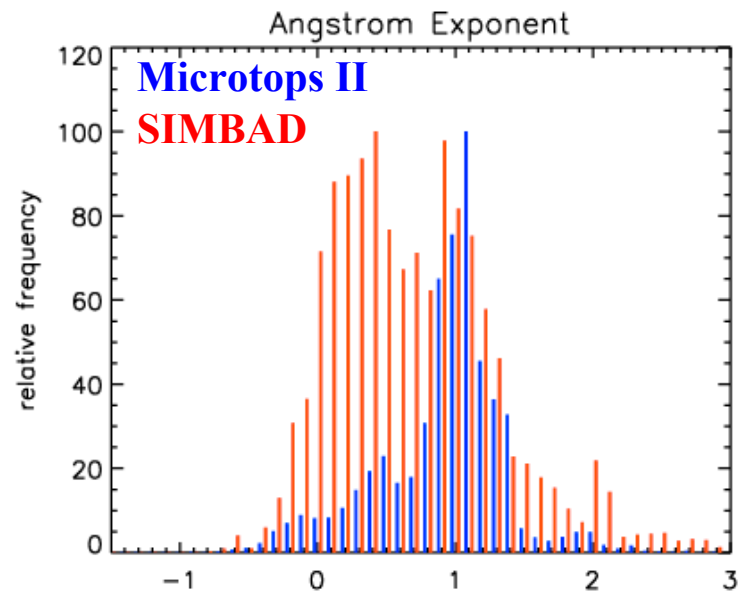
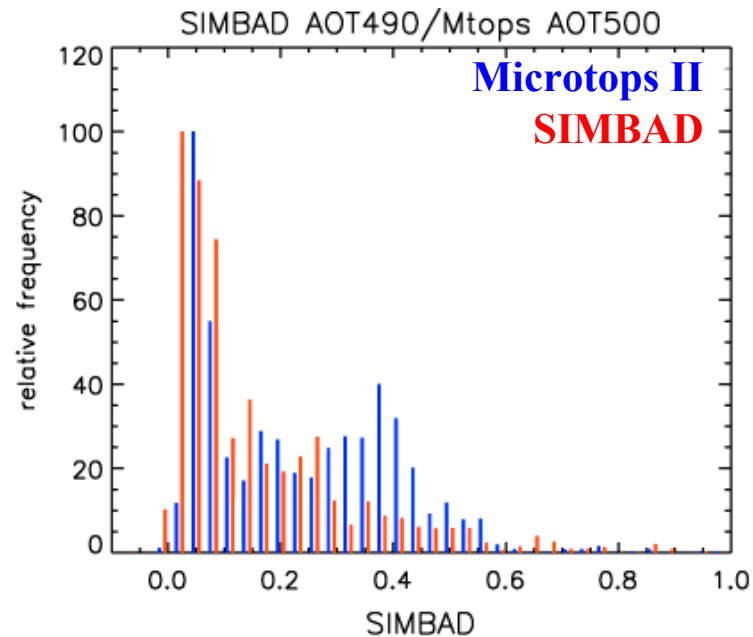
# Instrument Pool validation during ACE-Asia

- ACE-Asia was ideal for sun photometer validation
  - **Instruments: FRSR, SIMBAD, SIMBADA and 2 Microtops II's**
  - **Calibration was performed by a variety of means**
  - **Encountered a variety of aerosol conditions**
- Hand held sun photometer AOT and Angstrom Exponent values agree within uncertainties in all situations, although Angstrom uncertainty values are large
- FRSR data underestimation in large AOT's, algorithm modified to remove effect
- Detailed analysis to be submitted to JGR ACE-Asia special issue.



# Hand Held Sun Photometer Statistics

## Entire Microtops II and SIMBAD dataset



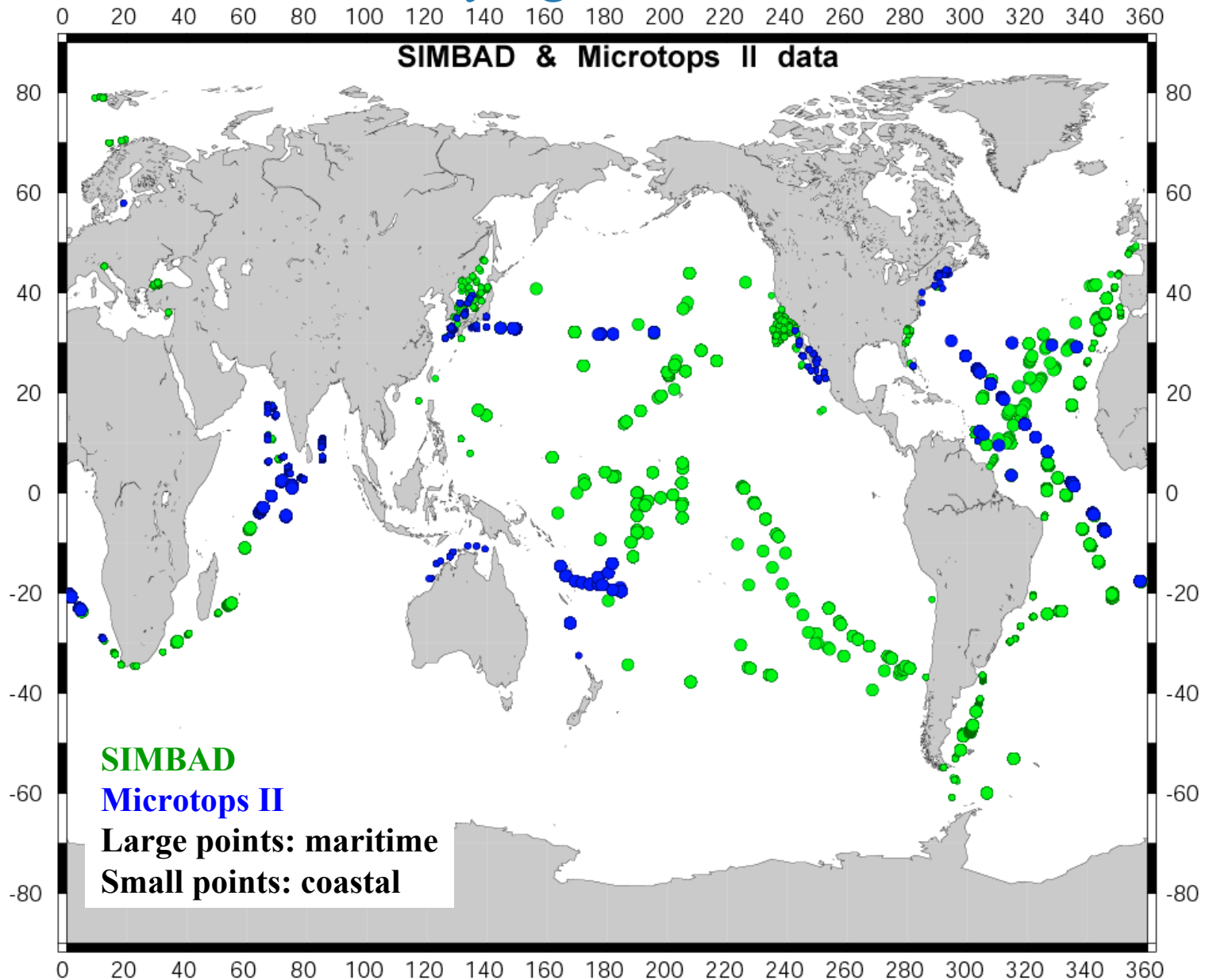
From  
Smirnov,  
et al. 2002

Biomass  
Burning

Maritime

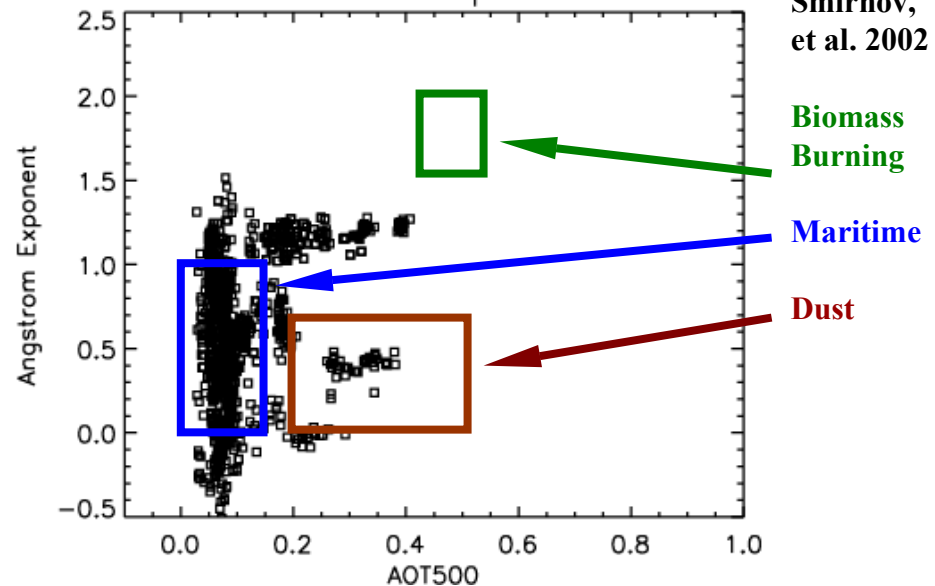
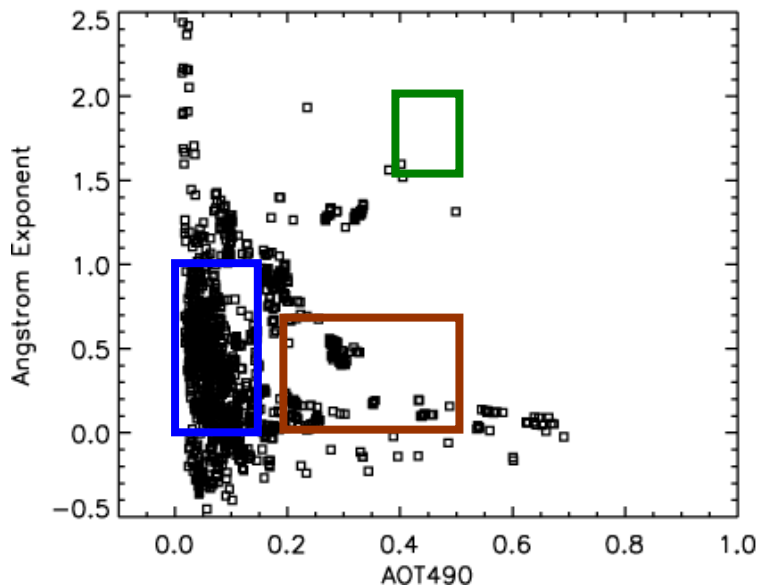
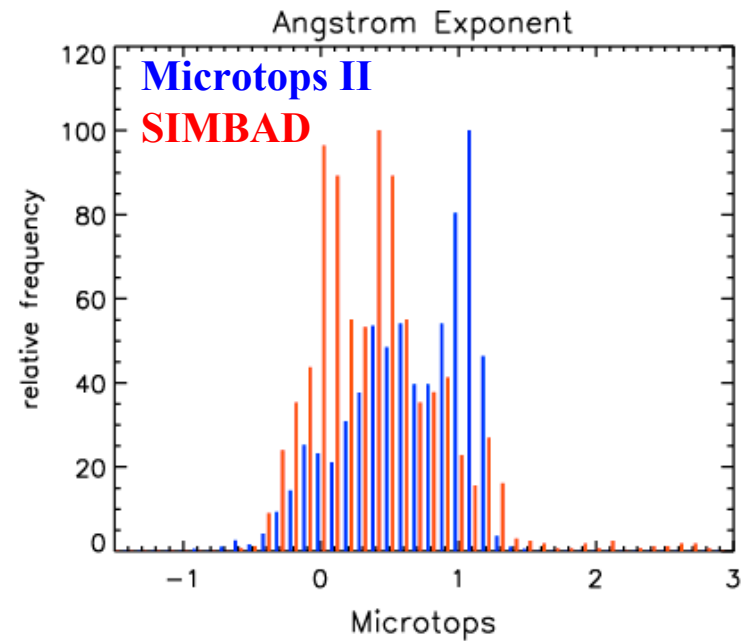
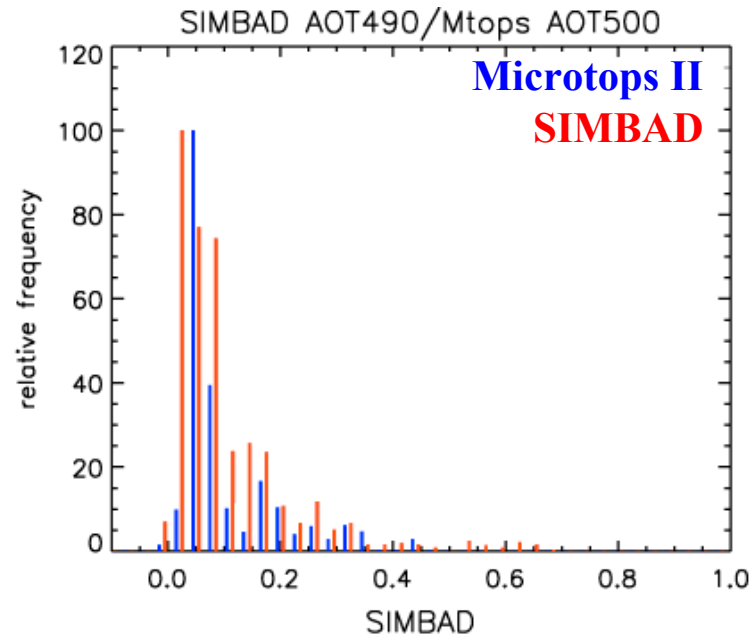
Dust

# Identifying Maritime Data



# Maritime Hand Held Sun Photometer Statistics

Microtops II and SIMBAD dataset restricted to offshore locations



From  
Smirnov,  
et al. 2002

# Maritime Hand Held Sun Photometer Statistics

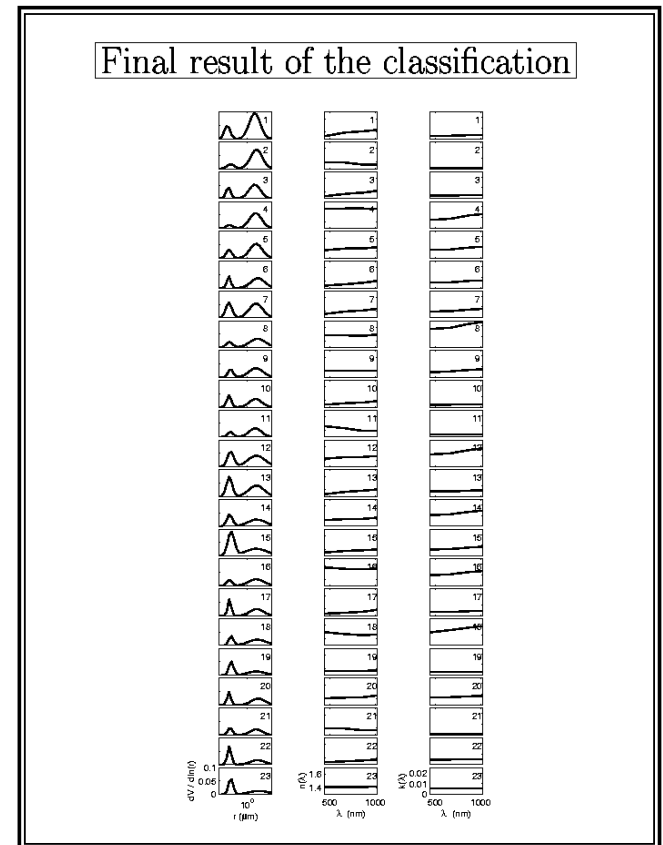
Dataset	N	AOT 500 mean	AOT 500 STD	Angstrom mean	Angstrom STD
<b>Microtops II, Maritime</b>	<b>1359</b>	<b>0.11</b>	<b>0.09</b>	<b>0.69</b>	<b>0.43</b>
<b>SIMBAD, Maritime</b>	<b>1490</b>	<b>0.12</b>	<b>0.11</b>	<b>0.47</b>	<b>0.49</b>
Lanai CIMEL, Pacific*	722	0.07	0.05	0.76	0.37
Nauru CIMEL, Pacific*	276	0.08	0.03	0.43	0.35
Tahiti CIMEL, Pacific*	234	0.07	0.02	0.74	0.27
Bermuda CIMEL, Atlantic*	590	0.14	0.09	0.93	0.41
Ascension CIMEL, Atlantic*	338	0.13	0.07	0.62	0.30

\*CIMEL data from Smirnov et al., 2002

# Model construction efforts

- **SeaWiFS/MODIS Oceans models, based upon Shettle and Fenn, 1979, perhaps need an update**
- **Miller and Wang (SIMBIOS PI's) investigating building models from FRSR data**
- **Frouin (SIMBIOS PI) and Gross building models with AERONET and SeaBASS data**
  - Probabilistic Self-Organizing Map (neural network)
  - Hierarchical Clustering

PSOM results for CIMEL data



# Conclusions

- **SIMBIOS deploys sun photometers to maritime regions missing from other data sets**
  - **Data collected in true maritime conditions on ships - coverage of 2/3 of planet inaccessible to land based sun photometers.**
  - **Avoid adjacency effect, coastal aerosols encountered in island sites**
- **SIMBIOS performs rigorous instrument cross-calibration to AERONET CIMELs and GSFC lamp sources**
- **ACE-Asia results validate the consistency between instruments in varied atmospheric conditions**
- **Statistics of maritime data compare to previously published literature, AERONET CIMELs**
- **AOT vs. Angstrom Exponent plots show a variety of atmospheric conditions, useful for**
  - **Satellite data match-up and validation**
  - **New aerosol model inputs**



# SIMBIOS Team

<http://simbios.gsfc.nasa.gov>

<http://seabass.gsfc.nasa.gov>

<http://seadas.gsfc.nasa.gov>



## Acknowledgments

We would like to express our thanks to the SIMBIOS PI's who have been collecting data and developing instruments since 1997. Thanks also to Jeremy Werdell for maintaining and ensuring the quality of SeaBASS data. We are also very grateful to the many PI's and site managers at all the AERONET stations. Finally, thanks to Giulietta Fargion, SIMBIOS Program Manager.

## Tools:

**SeaDAS NASA GSFC**

<http://seadas.gsfc.nasa.gov>

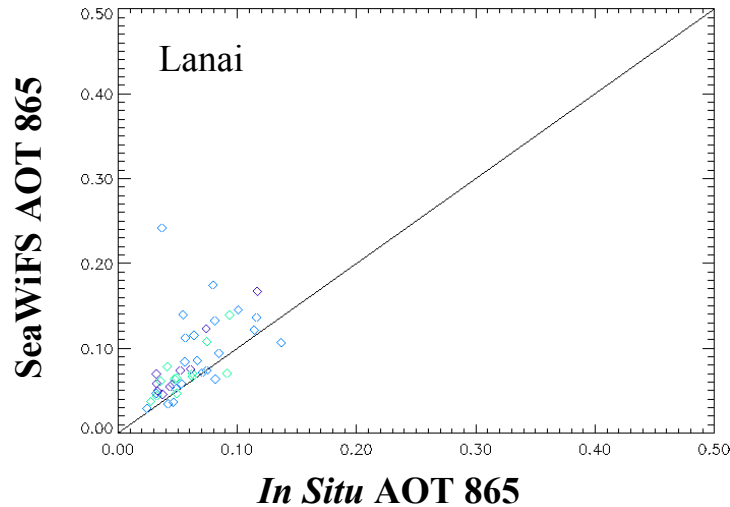
**HDFLook University of Lille**

<http://loa.univ-lille1.fr>

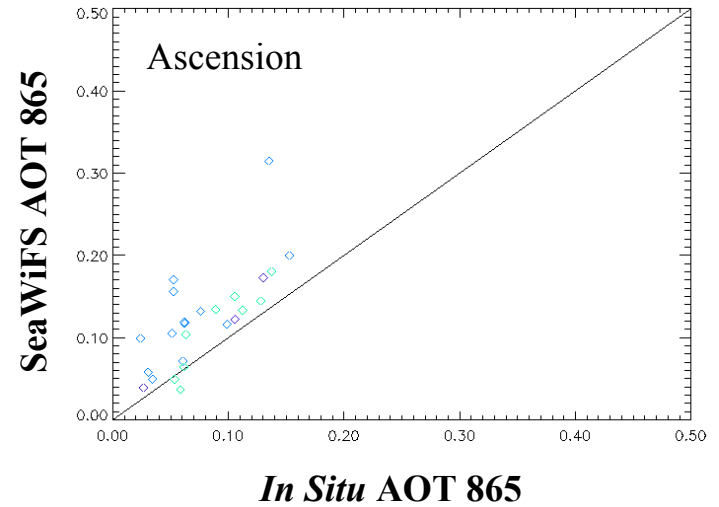
# Reserve

# Lanai and Ascension Islands

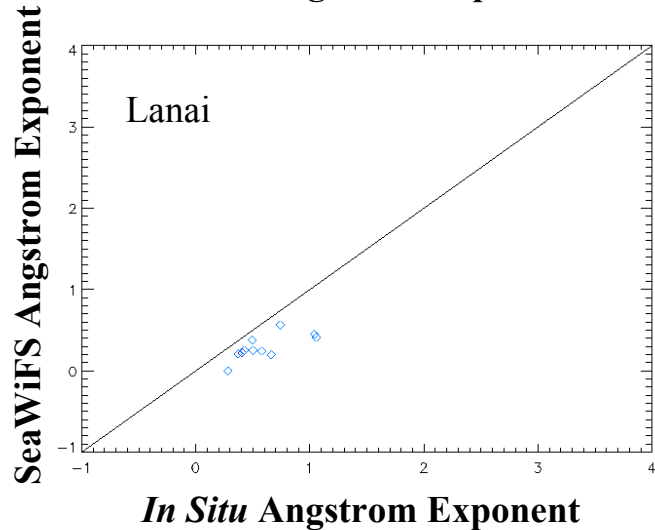
**SeaWiFS - *In Situ* matchups for AOT 865nm**



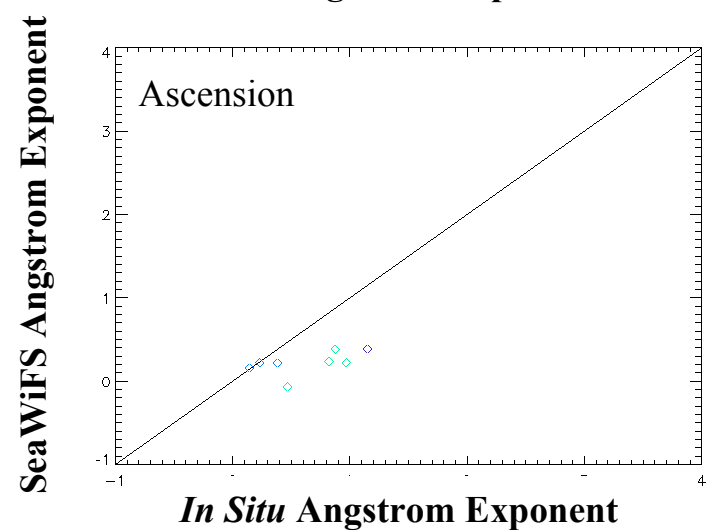
**SeaWiFS - *In Situ* matchups for AOT 865nm**



**SeaWiFS - *In Situ* Angstrom Exponent matchups**

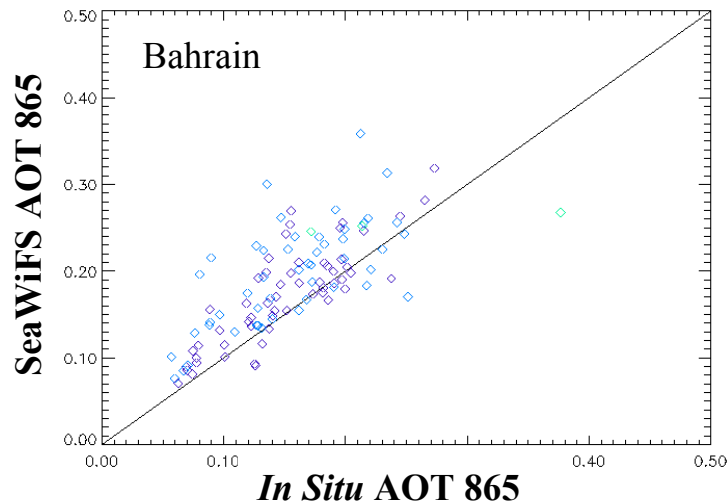


**SeaWiFS - *In Situ* Angstrom Exponent matchups**

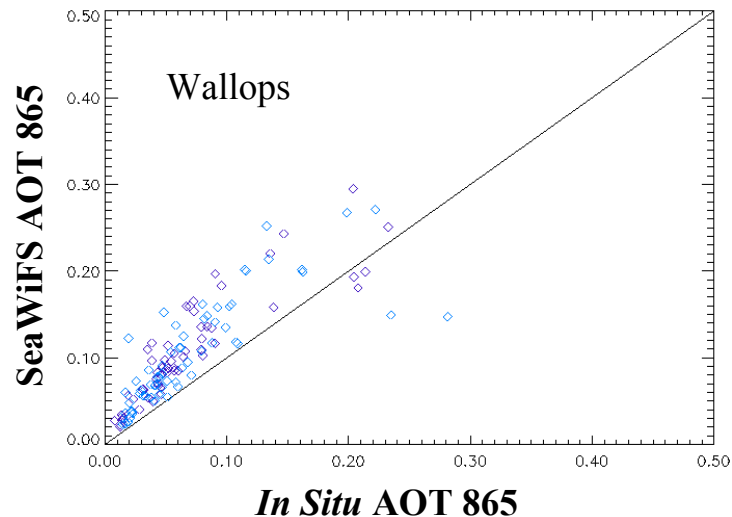


# Bahrain and Wallops

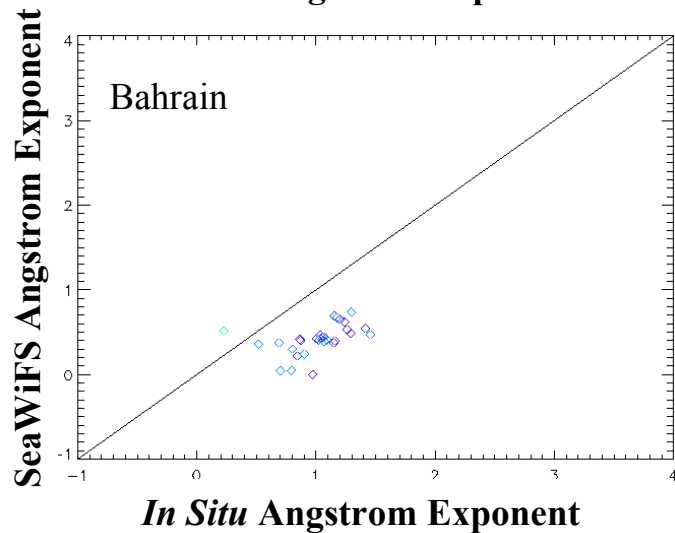
**SeaWiFS - *In Situ* matchups for AOT 865nm**



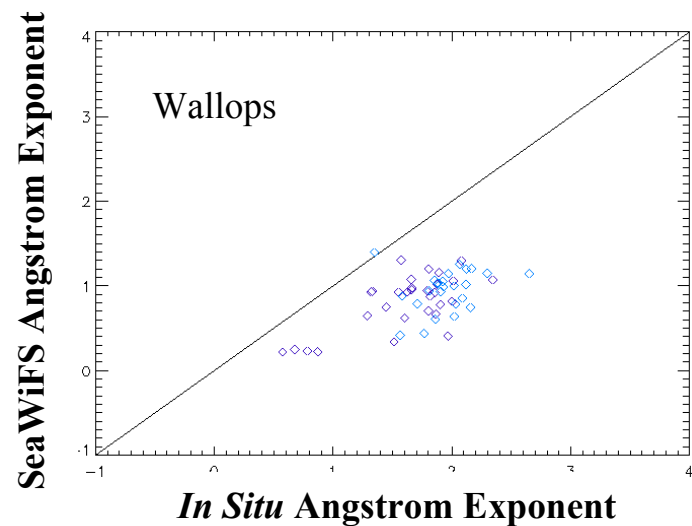
**SeaWiFS - *In Situ* matchups for AOT 865nm**



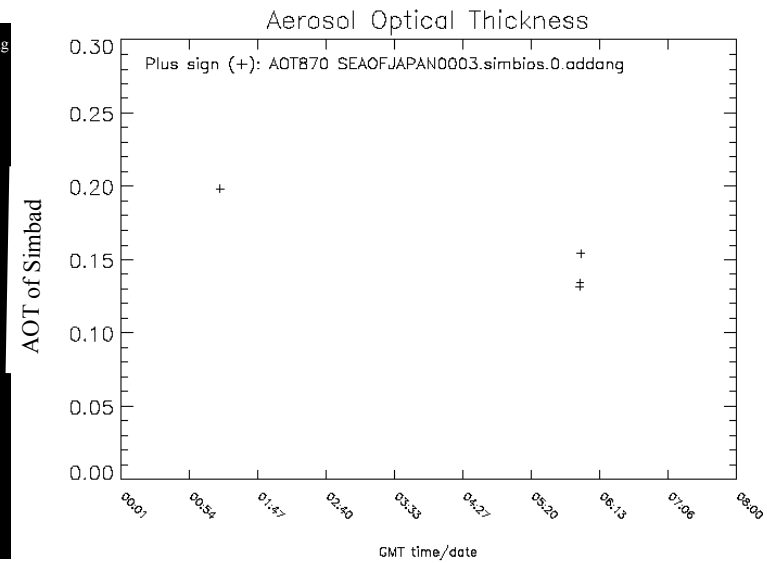
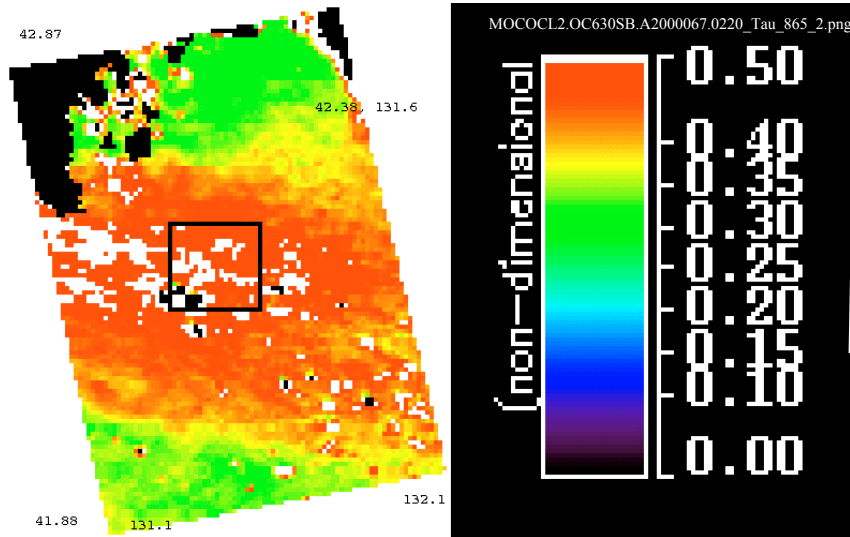
**SeaWiFS - *In Situ* Angstrom Exponent matchups**



**SeaWiFS - *In Situ* Angstrom Exponent matchups**



# Sea of Japan 2000/03/07



**SZA=55°**  
**Cloud coverage~30%**  
**Windspeed~20m/s**

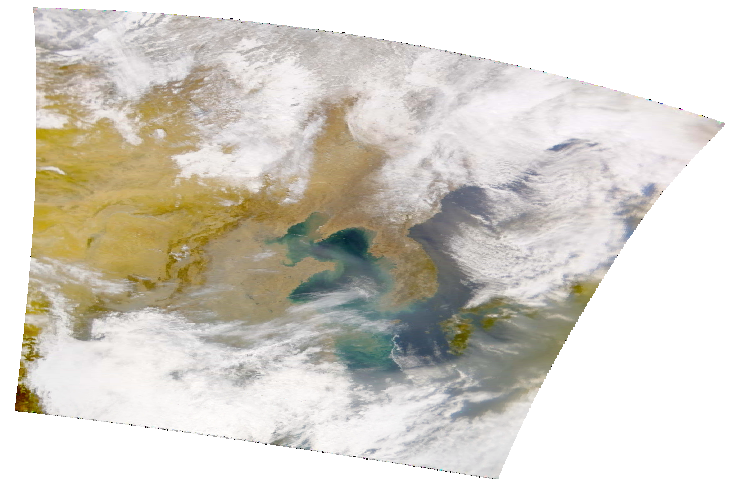


Image courtesy of Norman Kuring

Not Used

# Challenge

- Set goals: accuracy/precision
- Define *in situ* variables to be measured or derived from measurements, for satellite ocean color sensor validation, and algorithm development and validation
- Group them in “required”, “highly desired” & “specialized measurements” &... have the investigators collected them

What is needed?

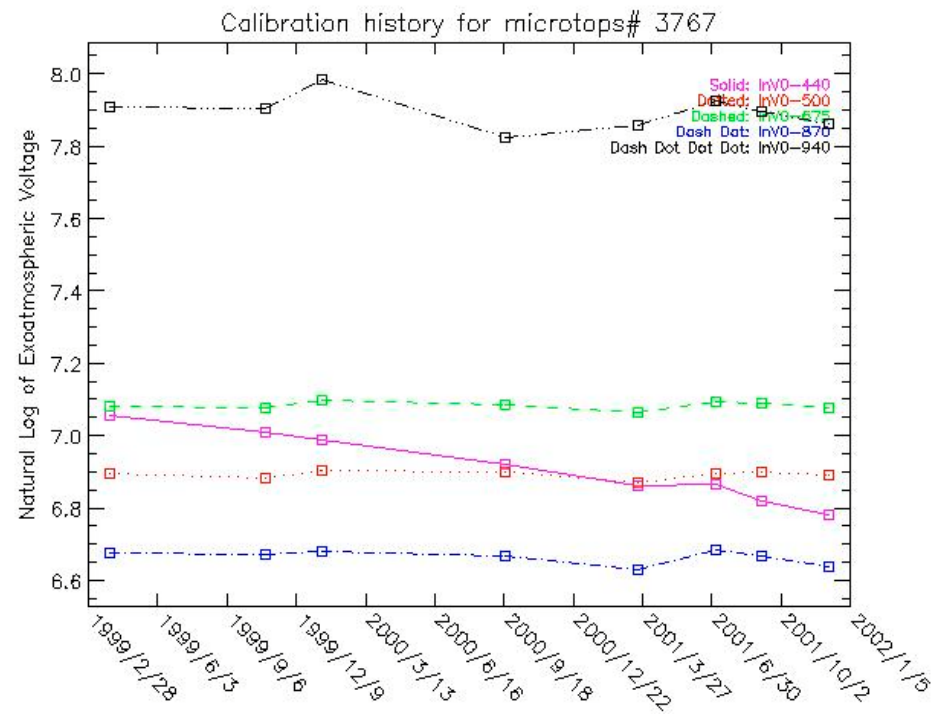
- **clear definition** of observations wanted
- **uncertainties** and source of errors
- data collection **protocols**
- instrument **performance** specification
- **calibration protocols** for all the instruments

What is currently in place

- **Investigators** collecting global *in situ* data, others working on **bio-optical** and **atmospheric** algorithms (i.e., NRA-99)
- **R&D** to investigate specific topics (SXR, SQM developmt.)
- **Collaborations** with Agencies
- Processing and analysis capability
- A system to document info (NASA TM)
- Protocols in place with frequent updates
- **Round robin** of data and of calibration facilities
- ***In situ* database** & satellite data holdings



# Sun Photometer Calibration Activities

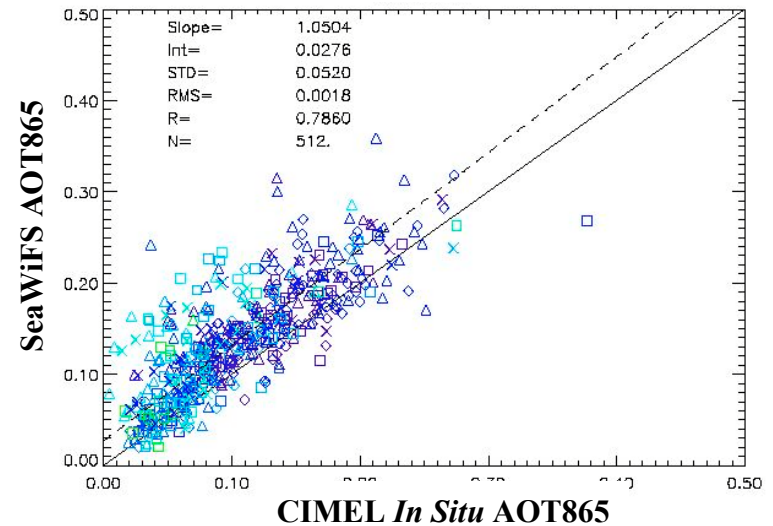


# Match-up Results - *CIMEL sun photometers*

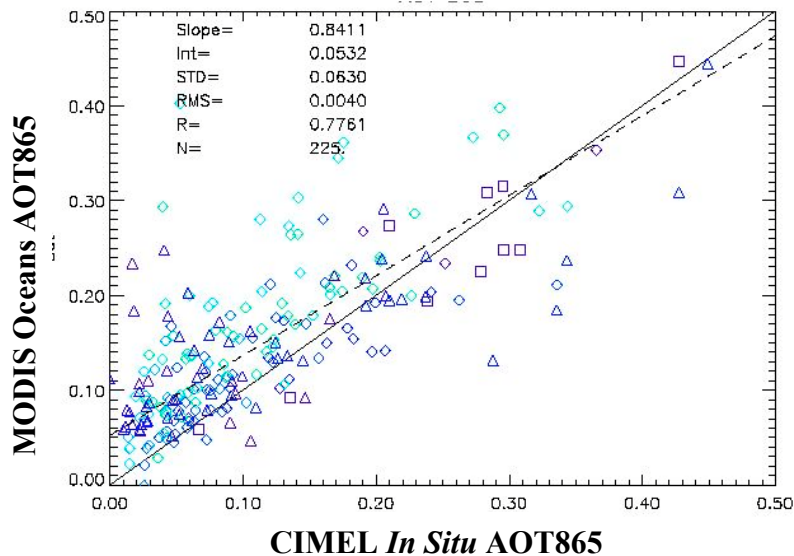
***In Situ* data is matched to spatially and temporally concurrent satellite data**

**Below are matchups for AOT 865nm collected with CIMELS  
Cloud screened quality control data set was used.**

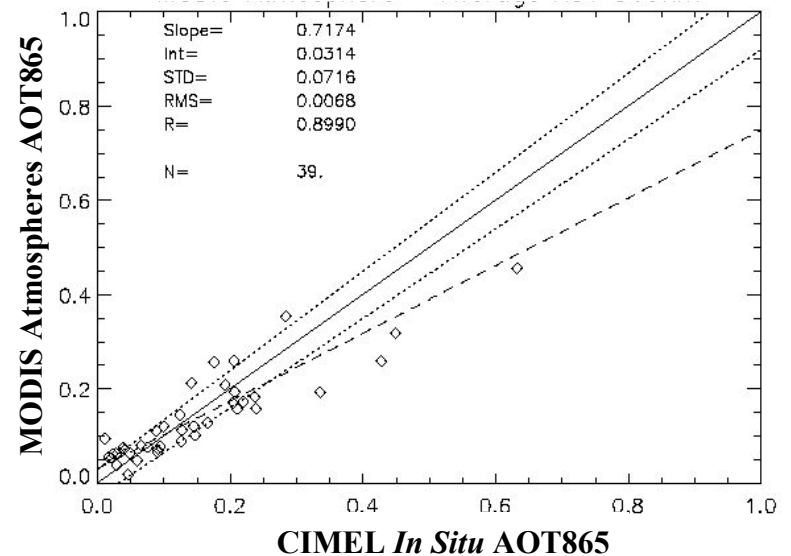
**SeaWiFS - *In Situ* matchups AOT at 865nm**



**MODIS Oceans - *In Situ* matchups AOT at 865nm**



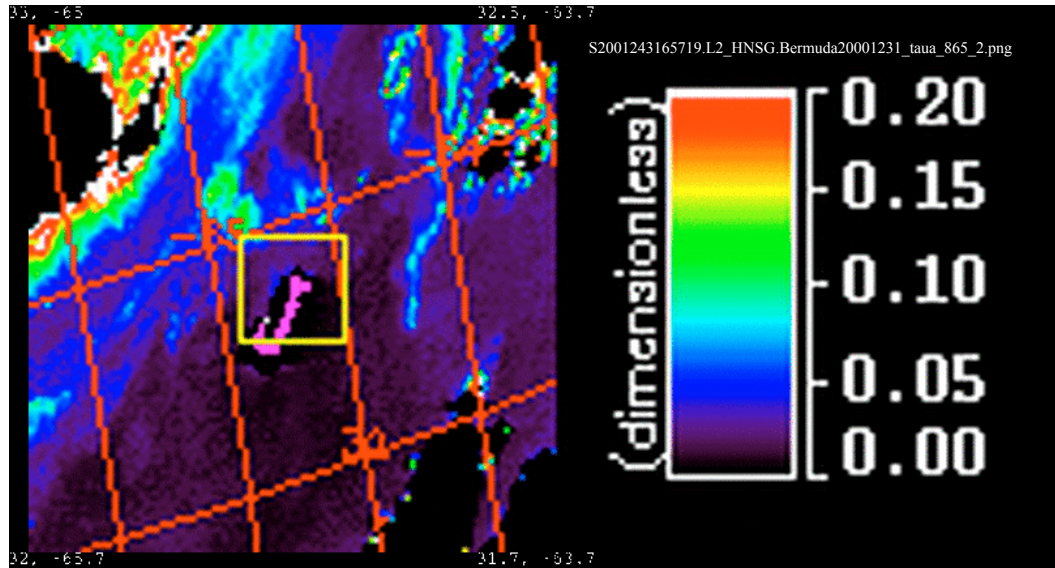
**MODIS Atmospheres - *In Situ* matchups AOT at 865nm**



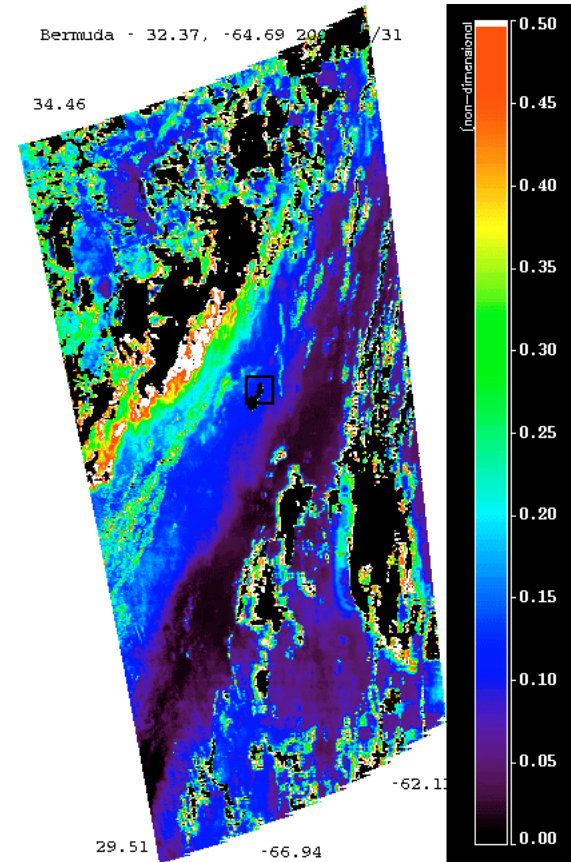
SeaWiFS

# Satellite AOT Products

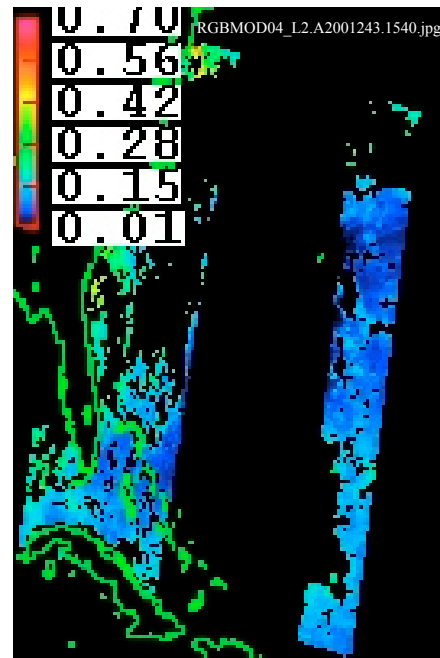
Over Bermuda on 2001/08/31



MODIS Oceans



MODIS  
Atmosphere

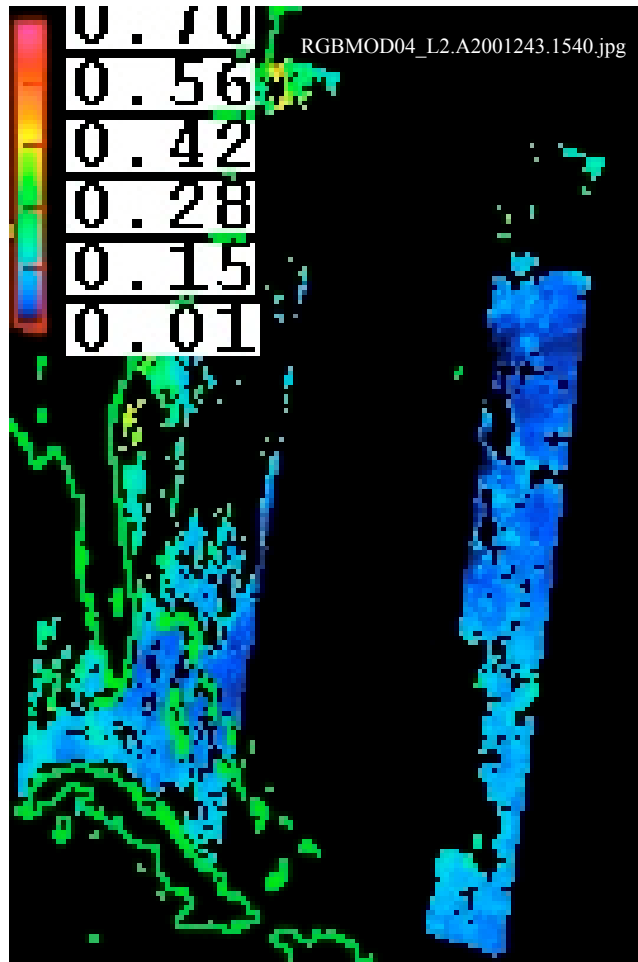


MOCOCL2.OCBATS.A2001243.1540\_Tau\_865.png

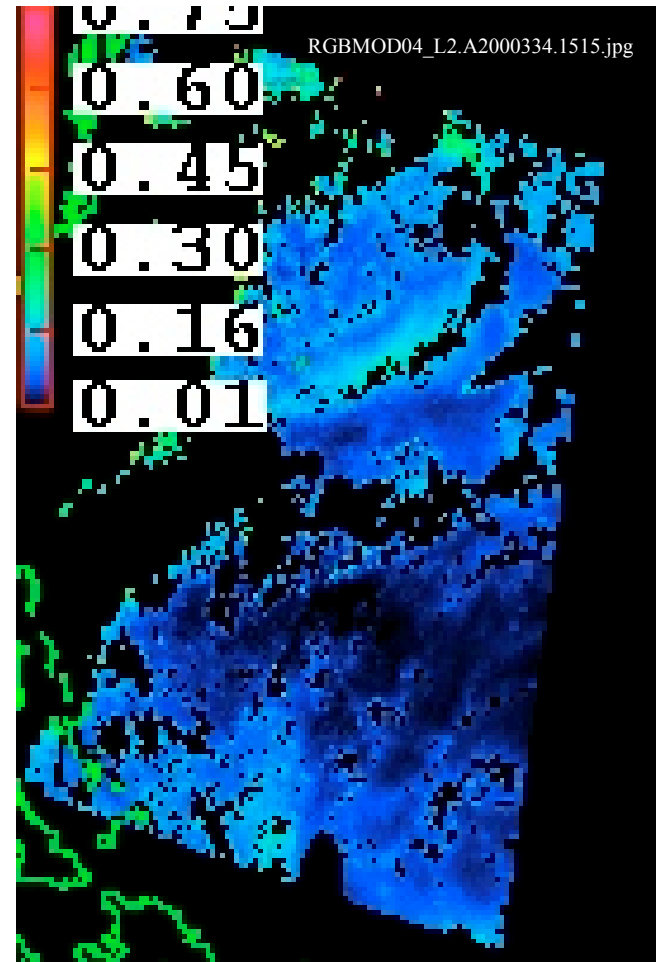
*Change image, small color scale  
etc..*

# Over Bermuda

2001/08/31

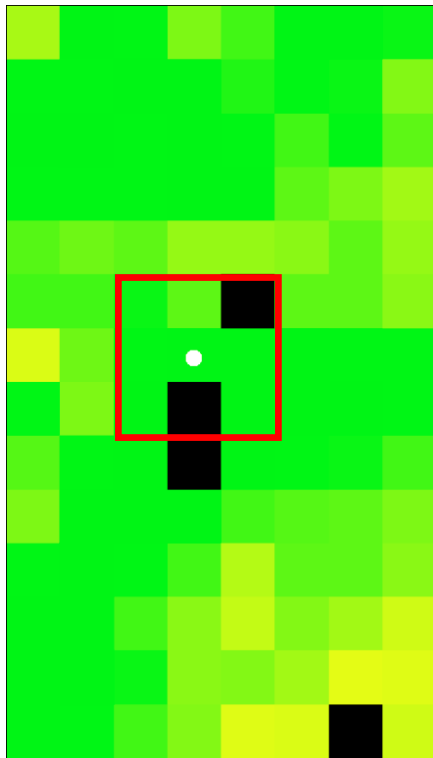


2000/11/29

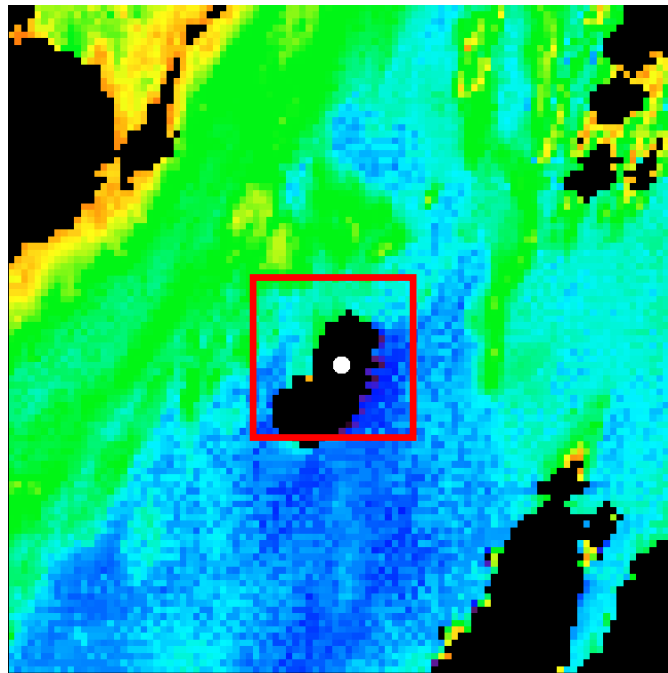


# Satellite AOT Products

**MODIS**  
**Atmosphere  $\tau_{865}$**



**SeaWiFS  $\tau_{865}$**



**MODIS Oceans  $\tau_{865}$**

